STRUCTURAL CALCULATION OF DIVERSION TUNNEL LINING

[UPPER TRISHULI-1 HEP (216MW)]

2022. 06. 04

DOOSAN Doosan Heavy Industries & Construction

FOR APPROVAL

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Project

Upper Trishuli-1 HEP (216MW)

Owner

NWEDC
NEPAL WATER AND ENERGY DEVELOPMENT CO. PVT.LTD.

Owner's Engineer

TRACTEBEL ENGIE

jade CONSULT

Contractor

DOOSAN Doosan Heavy Industries & Construction

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1 General

1.1 Background

Upper Trishuli-1 HEP is a project that uses the Trishuli River near Dunche and Haku. The construction site is located at rugged mountain between Tibet in China and the Himalaya Mountain which place 70 km away from capital, Kathmandu, towards the northwest. The headwork site is at 280m downstream from the confluence of Bhotekoshi and Trishuli rivers. The powerhouse site is 500m upward from Mailun Dobhan where Haku VDC is placed. The installed capacity of Upper Trishuli-1 HEP is 216 MW as a Run of River type. It is a year-round power plant which can generate about 1,533.4 GWh within a year.

The diversion tunnel is located on the right bank of Trishuli River. The cross section is a reversed 'D' shaped type (rectangular shape plus an arc section). The elevation of the inlet is EL. 1244.50m, and the elevation of outlet is EL. 1231.00m. The length of diversion tunnel is about 413.042 m and the longitudinal slope is 3.32%.

The profile of diversion tunnel is shown in Figure 1.1. The cross section is shown in Figure 1.2~1.5.

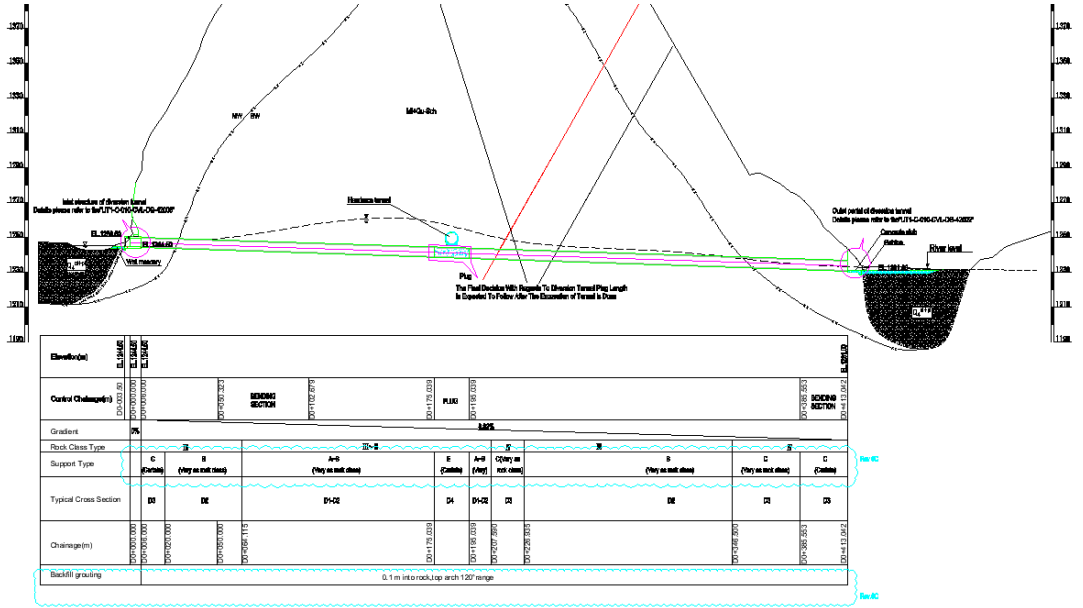


Figure 1.1 Profile section of diversion tunnel

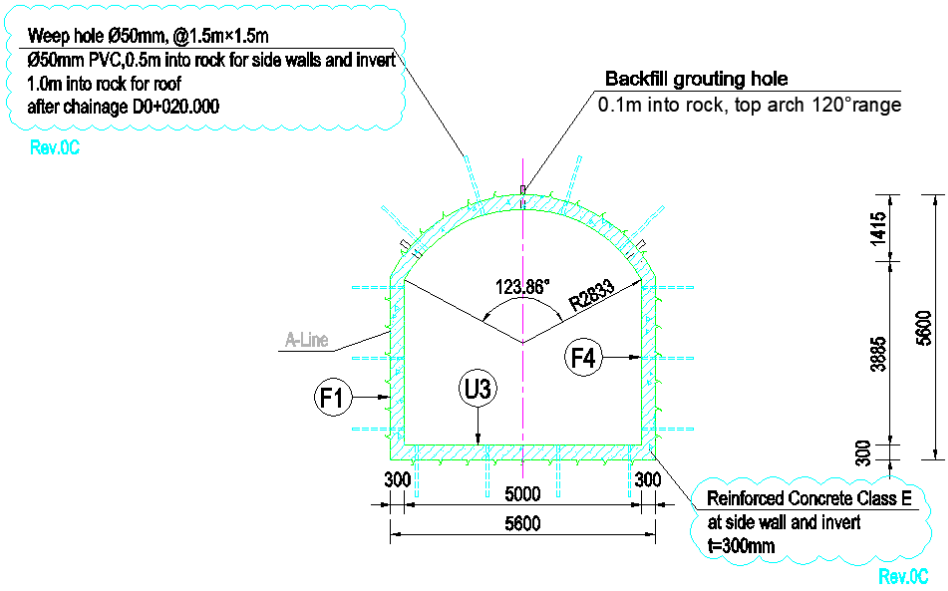


Figure 1.2 Typical section of diversion tunnel (Rock class II)

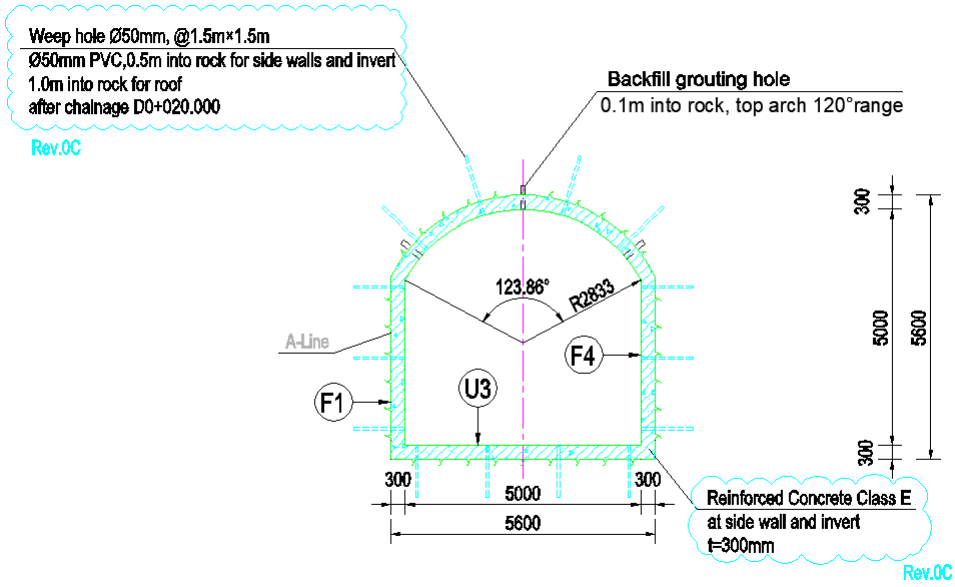


Figure 1.3 Typical section of diversion tunnel (Rock class III)

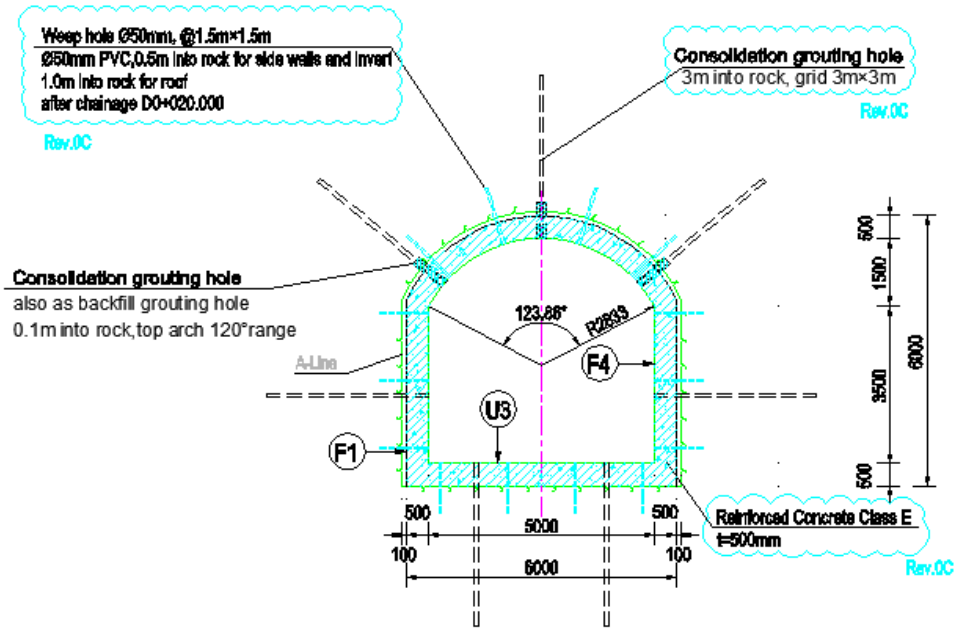


Figure 1.4 Typical section of diversion tunnel (Rock class IV)

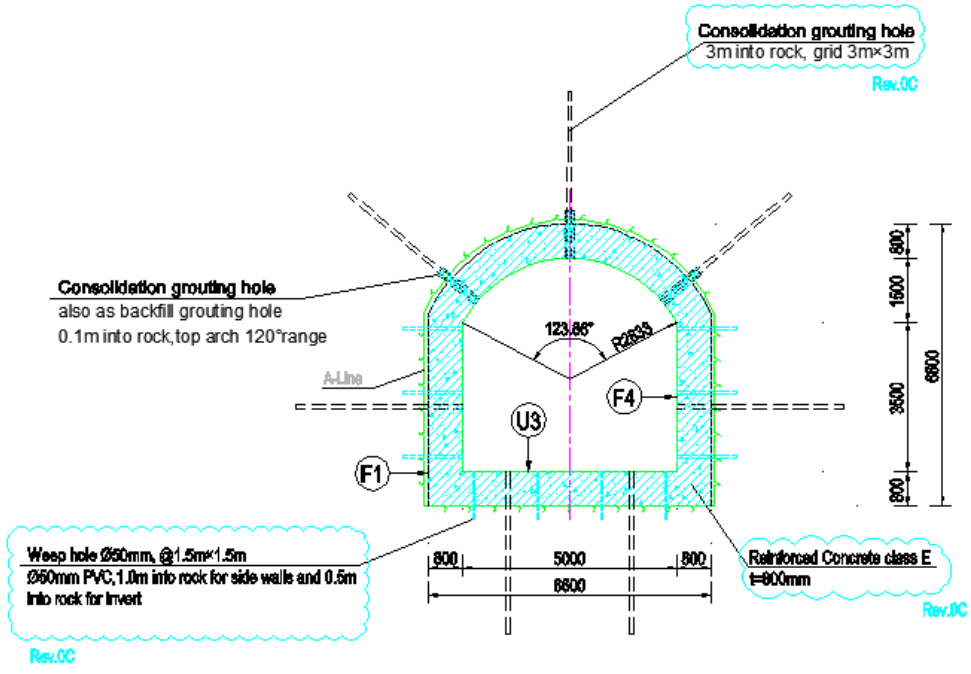


Figure 1.5 Typical section of diversion tunnel

(Intersection of headrace and diversion tunnel)

1.2 Design stage & software

This calculation is provided for detailed design stage.

The internal force (bending moment, axial force, shear) is calculated by Midas Gen, and the seepage pressure is calculated by Phase 2D.

MIDAS Gen is a 3D structural analysis and design system from MIDAS, the company's first commercial software. Its powerful calculation and analysis function meets the calculation and design requirements of conventional buildings, and it can also well complete the analysis and design of mixed structures and special structures.

Phase2 is a powerful 2D elasto-plastic finite element stress analysis program for underground or surface excavations in rock or soil. It can be used for a wide range of engineering projects and includes support design, finite element slope stability and groundwater seepage analysis.

1.3 Purpose and contents

Internal force of tunnel cross section is calculated with representative station numbers in line with arrangement of Diversion Tunnel, category of surrounding rock and pressure distribution of underground water, according to which reinforcements are configured to provide the basis for detail design of Diversion Tunnel. Please refer to Table 1.1 for table of station numbers at control section of Diversion Tunnel.

Table 1.1 Table of chainage at control section of diversion tunnel

No.	Starting chainage No.	Ending chainage No.	Surrounding Rock Class	Thickness of Lining (m)
1	D0+006.00	D0+020.000	III	0.5
2	D0+020.000	D0+064.115	III	0.3
3	D0+064.115	D0+175.039	II-III	0.3
4*	D0+175.039	D0+195.039	II-III	0.8
5	D0+195.039	D0+207.590	II-III	0.3
6	D0+207.590	D0+226.935	IV	0.5
7	D0+226.935	D0+346.500	III	0.3
8	D0+346.500	D0+413.042	IV	0.5

(Note: No. 4* is intersection of headrace and diversion tunnel)

2 Reference Document

2.1 Rules and regulations

(1) Tunnels and Shafts in Rock (EM 1110-2-2901);

(2) Strength Design for Reinforced Concrete of Hydraulic Structure (EM1110-2-2104);

(3) Building Code Requirements for Structural Concrete (ACI 318M).

2.2 Technical documents

(1) Arrangement Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42001)

(2) Hydraulic Calculation fo Diversion Tunnel (UT1-C-010-CVL-DC-42001)

(3) Excavaiton and Initial Support Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42003)

(4) Outline Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42005)

3 Calculation Process

3.1 Material characteristics and calculation parameters

(1) Concrete

a) Class E (Cylinder compressive strength is 24MPa)

Volume weight of reinforced concrete: 25.0kN/m³;

b) Elastic modulus and Poisson's ratio is shown in Table 3.1.

Table 3.1-1 Elastic modulus and Poisson's ratio

Elastic Modulus E_c (MPa)	Poisson's Ratio
2.3×10^4	0.2

(2) Reinforcement

a) Yield strength of deformed bar: 500MPa;

b) Yield strength of round bar: 280MPa;

c) Elastic modulus: 200,000MPa;

(3) Physical and mechanical parameters of rocks

Table 3.1-2 Mechanical parameter of diversion tunnel surrounding rock

Class of surrounding rock	Saturated compressive strength	Elastic modulus	Poisson ratio	Rock mass/rock mass shear (shearing) strength	
	(MPa)	(GPa)		Φ (°)	c′ (MPa)
II	13	20.5	0.25	48	2.5
III	4.2	7.5	0.27	45	1.0
IV	1.9	2.3	0.30	35	0.5

(4) water level in work condition

When the flood flow through the diversion tunnel in 5-year return period in flood season, the upstream water level is EL.1260.5m.

When the diversion tunnel is executed, the upstream water level is taken as zero, the diversion tunnel is empty inside.

When the Plugging is executed, the river flow will be discharged through the orifices of weir/dam, the upstream water level of weir/dam is 1247.6m, and the water level of diversion tunnel inlet is 1250.17m back calculated from weir/dam location.

3.2 Calculation principle and method

The calculation takes the method of bedded-beam-spring recommended in Chapter 9 of EM 1110-2-2901 Tunnels and Shafts in Rock that simulates lining section with MIDAS middle beam element and the arc length corresponding to every 5° central angle as the unit length and simulates interaction between lining and surrounding rock by applying normal and tangential spring gap elements to nodes. Reinforcements of lining section are configured according to result of internal force calculation. Figure 3.2-1 is illustration of concrete lining model.

Stiffness of spring elements is calculated by the following formulas:

For normal stiffness

$$k_r = E_r b\theta/(1+\nu_r)$$

For tangential stiffness

$$k_t = k_r G / E_r = 0.5k_r/(1+\nu_r)$$

Wherein:

k_r and k_t: Normal and tangential stiffness of springs; kN/m

E_r: Elastic modulus of surrounding rock; kPa. shown in the Table 3.2-1.

θ: Central angle of beam element; radian.

b: Calculative width; m.

G_r: Shear modulus of surrounding rock; kPa.

ν_r: Poisson's ratio of surrounding rock

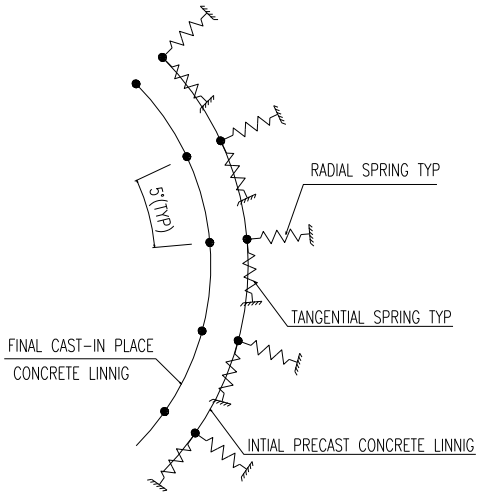


Figure 3.2-1 Illustration of concrete lining model

Gap Property

For each deformational degree of freedom you may specify independent gap ("compression-only") properties. See Figure 56 (page 258).

258 Gap Property

Chapter XV The Link/Support Element—Advanced

All internal deformations are independent. The opening or closing of a gap for one deformation does not affect the behavior of the other deformations.

If you do not specify nonlinear properties for a degree of freedom, that degree of freedom is linear using the effective stiffness, which may be zero.

The nonlinear force-deformation relationship is given by:

$$f = \begin{cases} \mathbf{k}\,(d + \mathbf{open}) & \text{if } d + \mathbf{open} < 0 \\ 0 & \text{otherwise} \end{cases}$$

where **k** is the spring constant, and **open** is the initial gap opening, which must be zero or positive.

The gap elements (springs) is installed in the all circumference (360° angel). The gap elements are also used for external pressure load cases. When the lining is bearing internal pressure, the gap element is equal to spring. In negative case, for example, external pressure case, it will separate lining from surrounding rock surface.

The method is regarding MIDAS program advance instruction book.

According to formulas in section 3.2, normal stiffness and tangential stiffness of rock class II,

rock class III and rock class IV are as listed in Table 3.2-1.

Table 3.2-1 Normal and tangential stiffness of surrounding rock (unit length)

Rock class	Normal Stiffness k_r (calculated with elastic modulus) (kN/m)	Tangential Stiffness k_t (calculated with elastic modulus) (kN/m)
Rock class II	5857142.9	2342857.1
Rock class III	2109111.4	830358.8
Rock class IV	570719.6	219507.5

In Midas Gen software, the roof arc beam is divided as about 25 elements, meanwhile the side walls and invert are divided as 14 elements. The z-direction displacement constraint is applied outside the plane. And the point spring constraints are used in the plane. The calculation elements dividing and load sketches in each case are as follows.

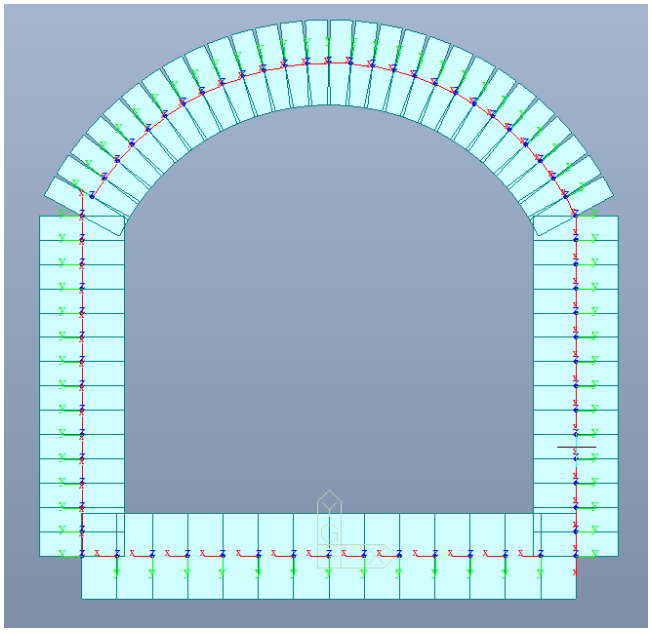


Figure 3.2-2 Elements of full concrete lining model

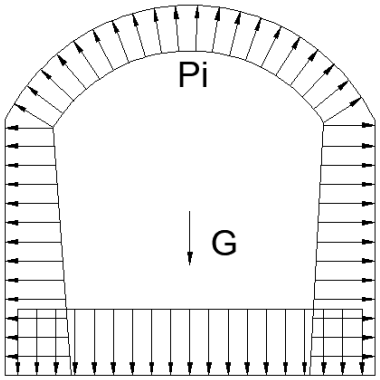


Figure 3.2-3 load sketch in case 1: self-weight load G, normal internal pressure Pi

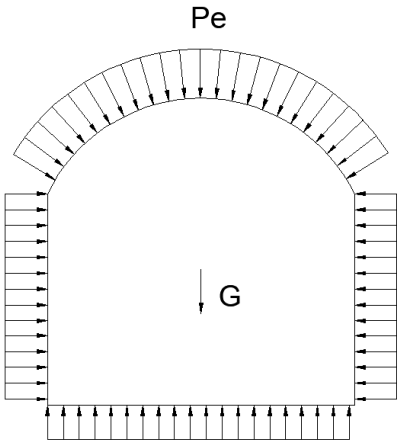


Figure 3.2-4 load sketch in case 2: self-weight load G, normal external pressure Pe

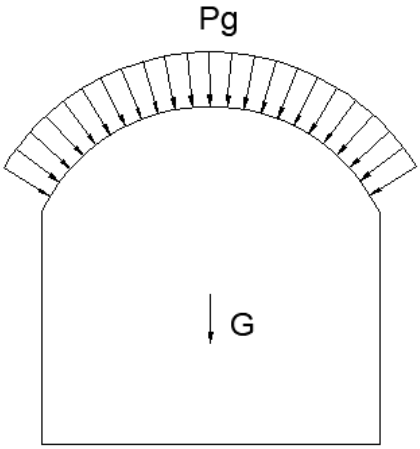


Figure 3.2-5 load sketch in case 3: self-weight load G, grouting pressure Pg, normal external pressure Pe

3.3 Combination of working conditions and calculation of loads

3.3.1 Combination of working conditions

According to table 9-1, EM1110-2-2901, loads acted on the lining include lining self-weight, internal water pressure, external water pressure, surrounding rock load, etc.

Additionally, it is reminded that according to the U.S.A.C.E. Manual EM 1110-2-2901, paragraph 9.4, item f: “In most cases, the rock is stabilized at the time the concrete lining is placed, and the lining will accept loads only from water pressure (internal, external, or both)."

So the surrounding rock load is taken into account in ***rock class IV and intersection***.

Loads and combination of working conditions are as stated in Table 3.3-1 and load factor under respective working condition is as listed in Table 3.3-2.

Table 3.3-1 Operation conditions and relevant loads

No.	Working Condition of Calculation	Self-weight	Internal Water Pressure	External Water Pressure	Grouting pressure
CASE1	Normal operation	√	√		
CASE2	Plugging	√		√	√
CASE3	Construction of D/T	√			√

Note: Only intersection and rock class IV consider surrounding rock load.

Table 3.3-2 Load factor under every working condition

No.	Working Condition of Calculation	Self-weight	Internal Water Pressure	External Water Pressure	Grouting pressure
CASE1	Normal operation	1.3	1.4		
CASE2	Plugging	1.1		1.4	1.4
CASE3	Construction of D/T	1.1			1.4

Note: Only intersection and rock class IV consider surrounding rock load and load factor is taken as 1.4.

3.3.2 Calculation of Loads

(1) Surrounding rock pressure

a) According to EM1110-2-2901, vertical rock pressure $q_{vk} = S_y \gamma_r H_A$, $S_y = 0.3$; horizontal rock pressure $q_{hk} = S_x \gamma_r H_A$, $S_x = 0.15$; of which H_A is excavation height of the tunnel, γ_r is surrounding rock weight, S_y is vertical rock pressure coefficient, S_x is horizontal rock

pressure coefficient.

for rock class IV:

Vertical rock pressure q_{vk}:

$$q_{vk} = S_y \gamma_r H_A$$

q_{vk}=0.3x26x5.5=42.9 kN/m.

Horizontal rock pressure q_{hk}:

$$q_{hk} = S_x \gamma_r H_A$$

q_{hk}=0.15x26x5.5=21.5 kN/m.

b) Intersection of headrace and diversion tunnel

Vertical rock pressure is calculated according to average rock thickness between headrace and diversion tunnel, which is about 3m.

Vertical rock pressure q_{vk}: q_{vk}=26x3=78 kN/m.

(2) Internal water pressure

The water level is at 1260.5m in 5-year return period flood whole year. The water level is 1250.17m in Plugging period. In diversion tunnel construction period, the diversion tunnel is empty inside,and the internal water pressure is zero.The internal water pressure is as follows.

Table 3.3-3 Table of internal water head of control section

No.	Control section Chainage	Surrounding Rock Class	Water Head (m)	Water pressure (kPa)
1	D0+020.000	III	16.5	161.70
2*	D0+195.039	II-III	22.3	218.54
3	D0+226.935	IV	23.5	230.30
4	D0+385.553	III	28.5	279.30

(Note: No. 2* is intersection of headrace and diversion tunnel)

3.3.3 Calculation of external water pressure

Regarding to《DESIGN OF CONCRETE LINENGS OF PRESSURE TUNNELS AND SHAFTS FOR EXTERNAL WATER PRESSURE》，the consolidation grouting reinforcement effect for surrounding rockmass is not taken into account. The permeability of the concrete lining is governed by the permeability of the uncracked concrete and mainly by the cracks, if any. the permeability of the uncracked concrete is normally below 10^{-8} m/s. in the concrete lining two kind of cracks can occur:

--radial cracks due to shrinkage and construction joints

--longitudinal cracks caused by internal water pressure

The the external water pressure reduced factor of rock class IV can be calculated by PHASE 2D software.

(1) Surrounding rock permeability parameters

Table 3.3-4 Permeability parameters of surrounding rock

Control section chainage	Rock class	Permeability Coefficient (m/s)	External water depth (m)	Weep holes
D0+020.000	III	$1e^{-7}$	80	Spacing 2.0mx2.0m, 0.3m depth into rock
D0+195.039 Intersection	II~III	$1e^{-8}$~$1e^{-7}$	220	Spacing 1.5mx1.5m, 1.0m depth into rock for roof and 0.5m depth into rock for side walls & invert
D0+226.935	IV	$1e^{-6}$	220	
D0+385.553	III	$1e^{-7}$	220	

(2) Seepage calculation model

The finite element model for rock class III & IV i and the corrponding hydraulic boundary are shown as folllows.

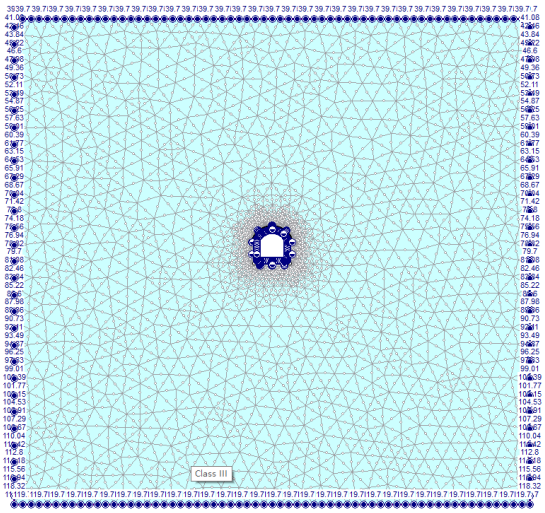


Figure 3.3-1 the finite element calculation model (weep holes 2mx2m)

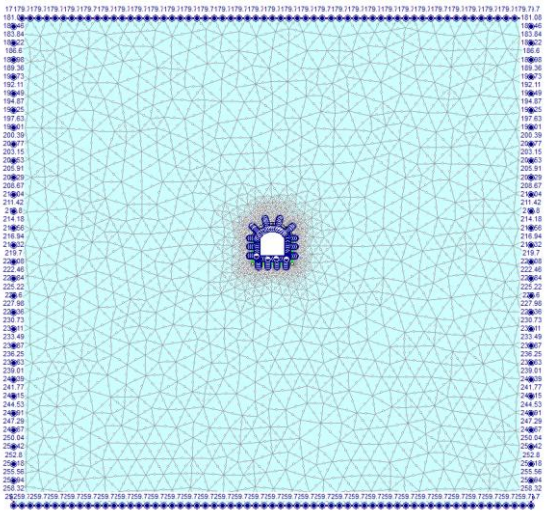


Figure 3.3-2 the finite element calculation model (weep holes 1.5mx1.5m)

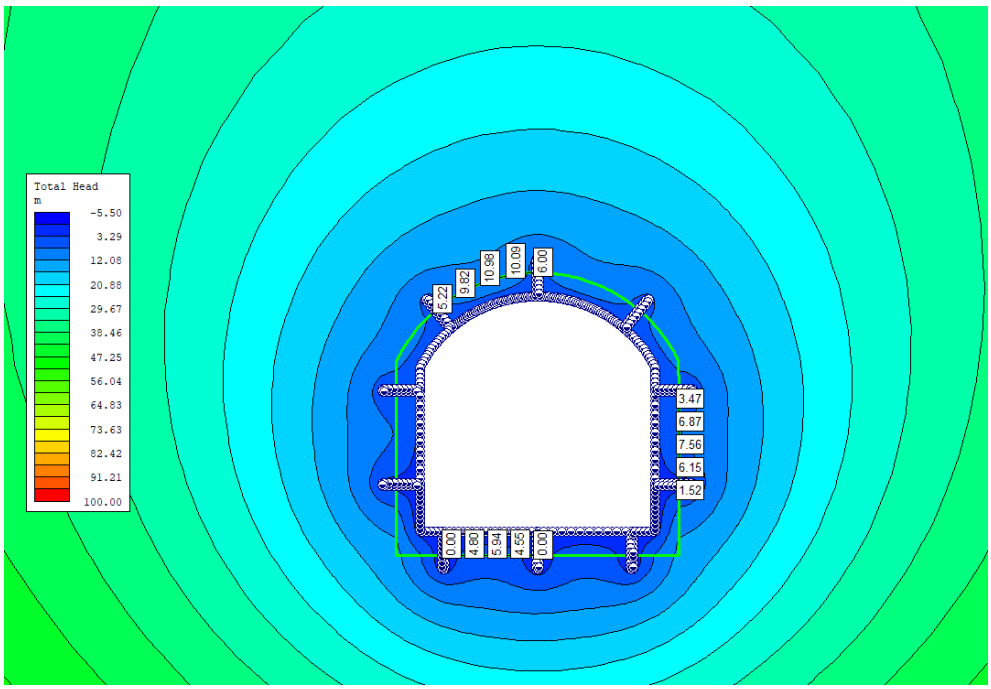


Figure 3.3-3 the seepage calculation result of intersection section chainage 0+020.00

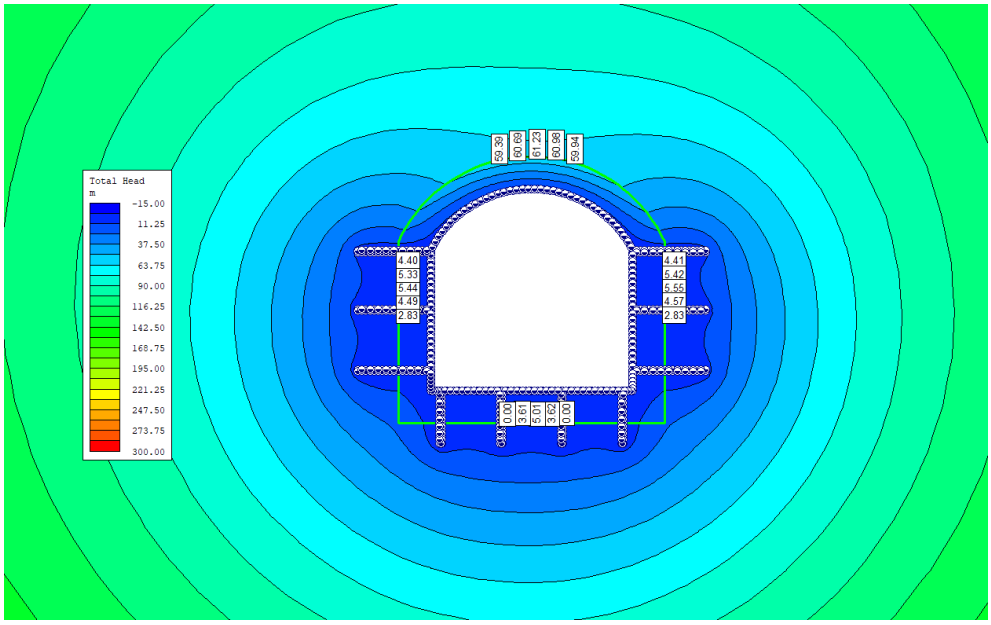


Figure 3.3-3 the seepage calculation result of intersection section chainage 0+195.039

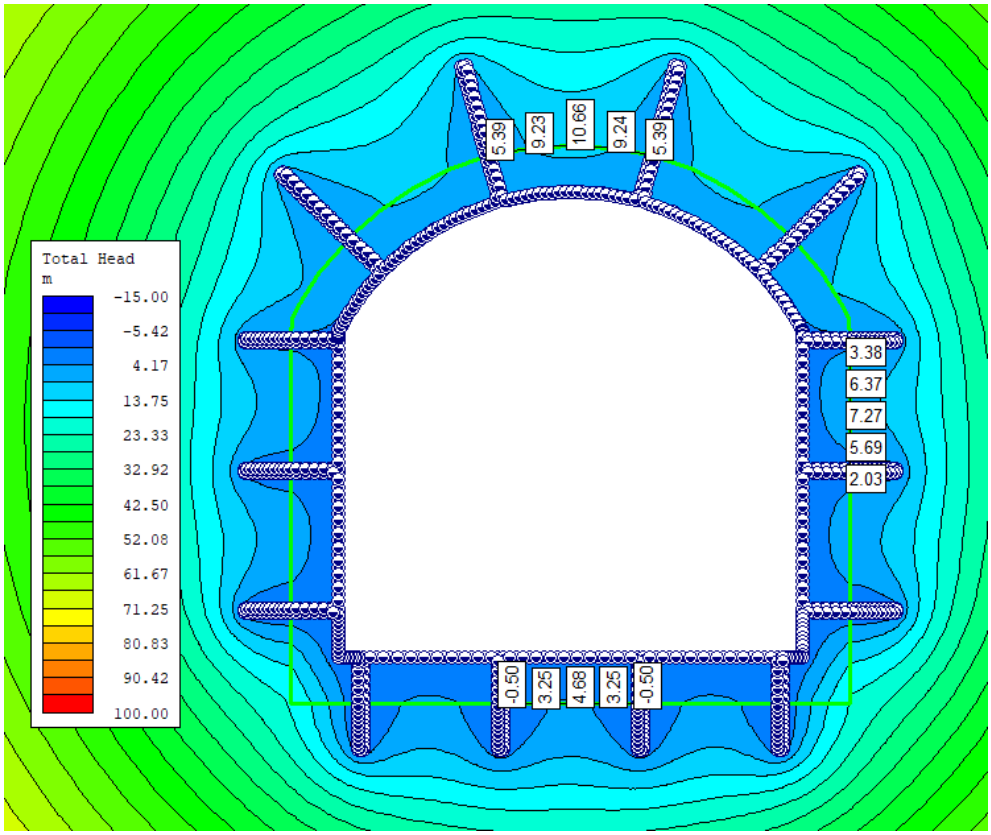


Figure 3.3-4 the seepage calculation result of section chainage 0+226.935

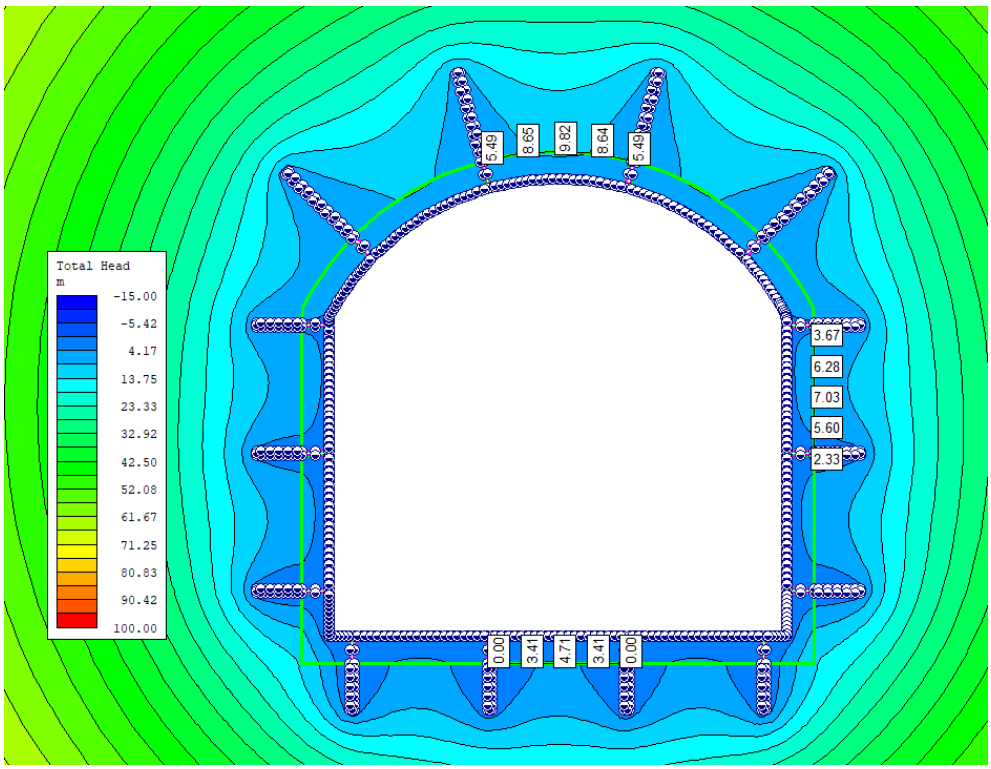


Figure 3.3-5 the seepage calculation result of section chainage 0+385.553

Table 3.7 Calculation of external water pressure

Chaiange	Rock class	Lining Thickness(m)	Roof water reduction Average value (m) /(kPa)	Side wall water reduction Average value (m)/(kPa)	Invert water reduction Average value (m)/(kPa)
D0+020.000	III	0.5m	8.5/83.3	5.5/53.9	3.0/29.4
D0+195.039 Intersection	II~III	0.8m	60.6/593.88	5.5/53.96	3.0/29.4
D0+226.935	IV	0.5m	8.4/82.32	5.6/54.88	2.9/28.42
D0+385.553	III	0.3m	7.7/75.46	5.4/52.92	2.4/23.52

4 Calculation Result

4.1 Figure of internal force

4.1.1 Figure of internal forces of concrete lining (Chainage 0+020.00)

The concrete lining from chainage 0+006.00 to 0+020.00, class III, concrete lining thickness 0.5m, double-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

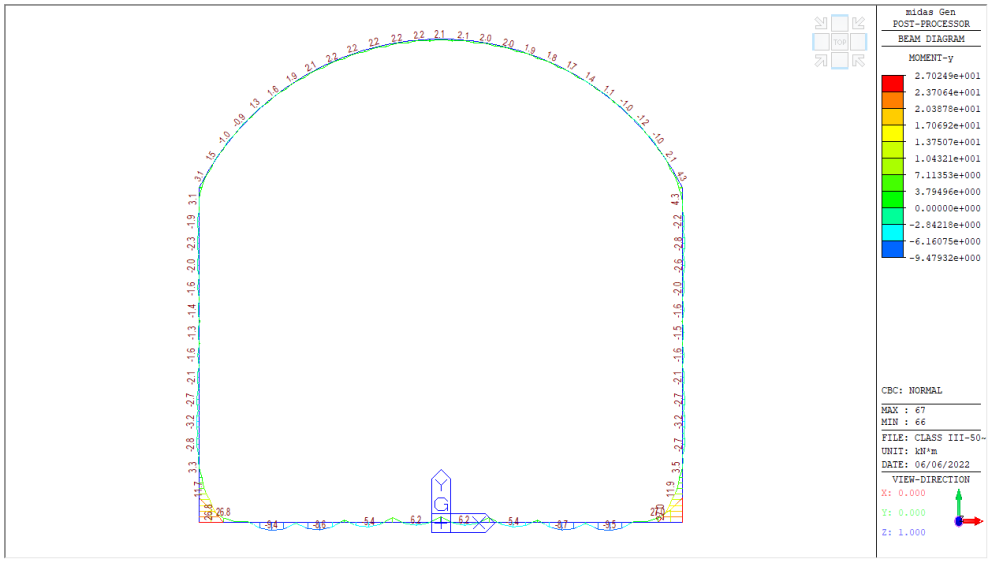


Figure 4.1.1-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

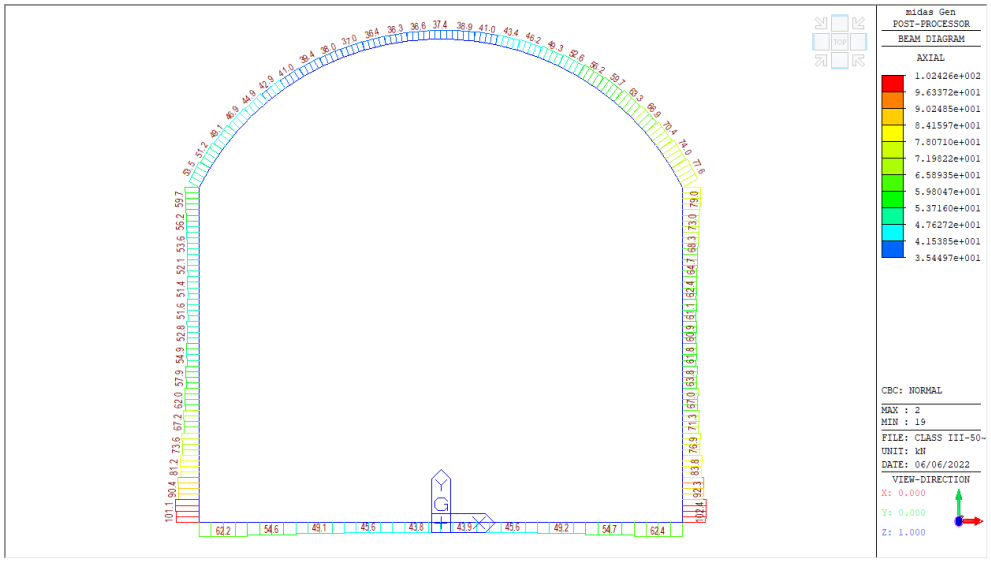


Figure 4.1.1-2 Figure of Axial Force at Concrete Lining Section (CASE1)

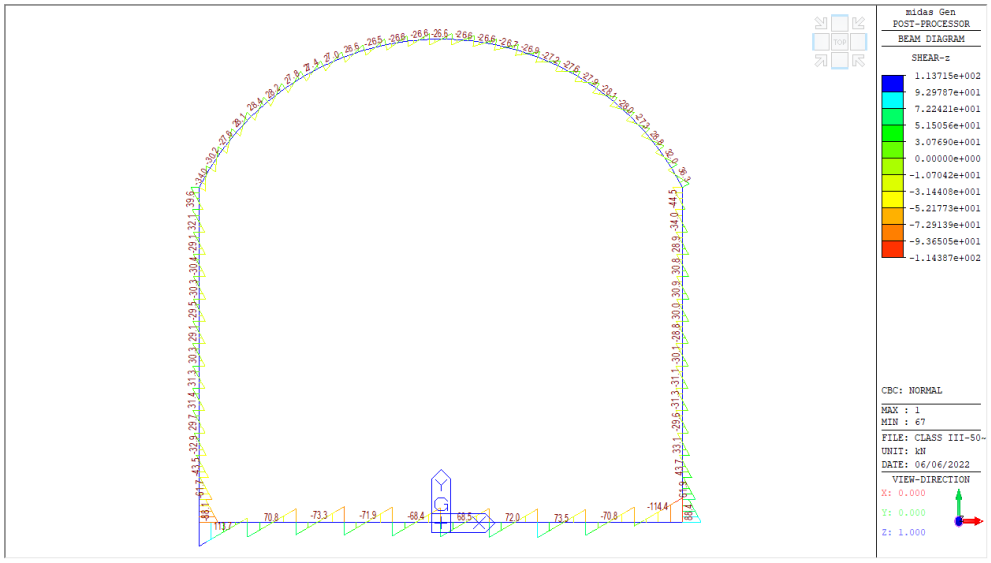


Figure 4.1.1-3 Figure of Shear Force at Concrete Lining Section (CASE1)

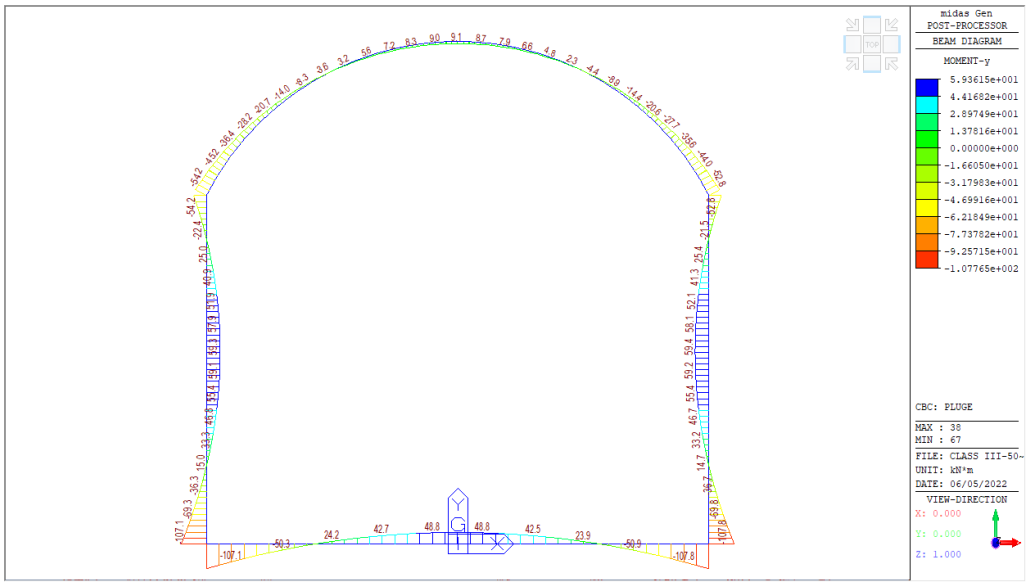


Figure 4.1.1-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

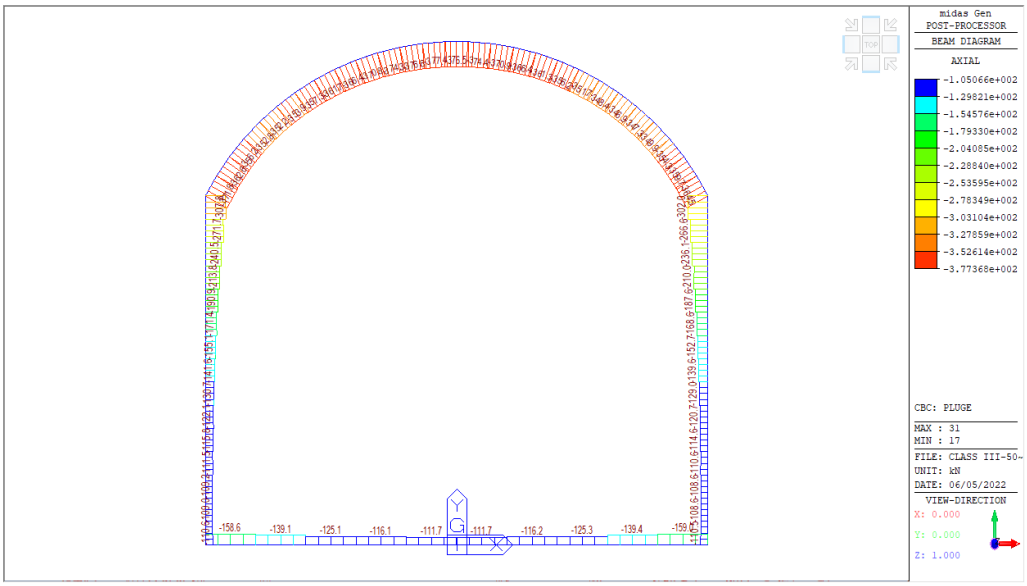


Figure 4.1.1-5 Figure of Axial Force at Concrete Lining Section (CASE2)

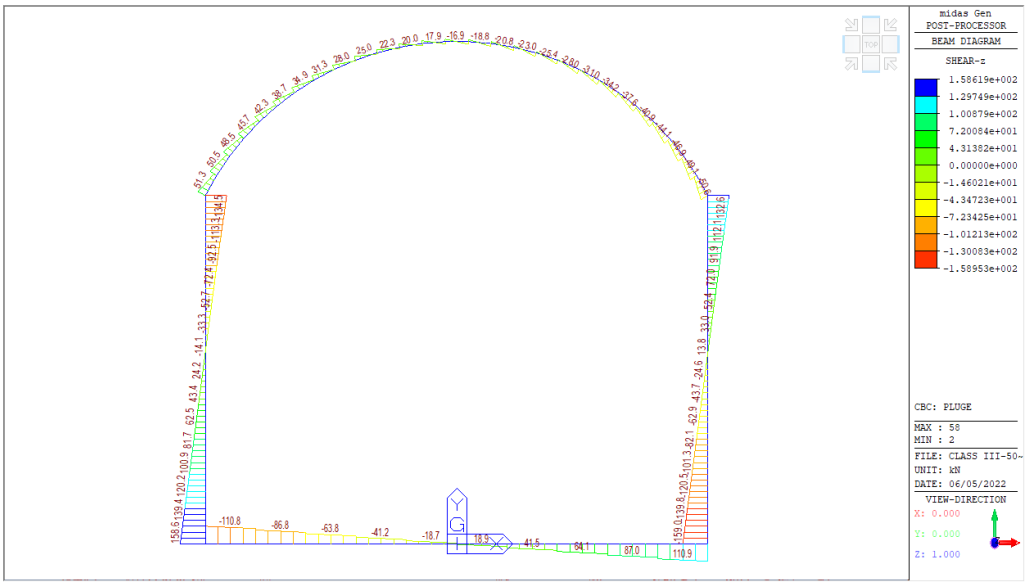


Figure 4.1.1-6 Figure of Shear Force at Concrete Lining Section (CASE2)

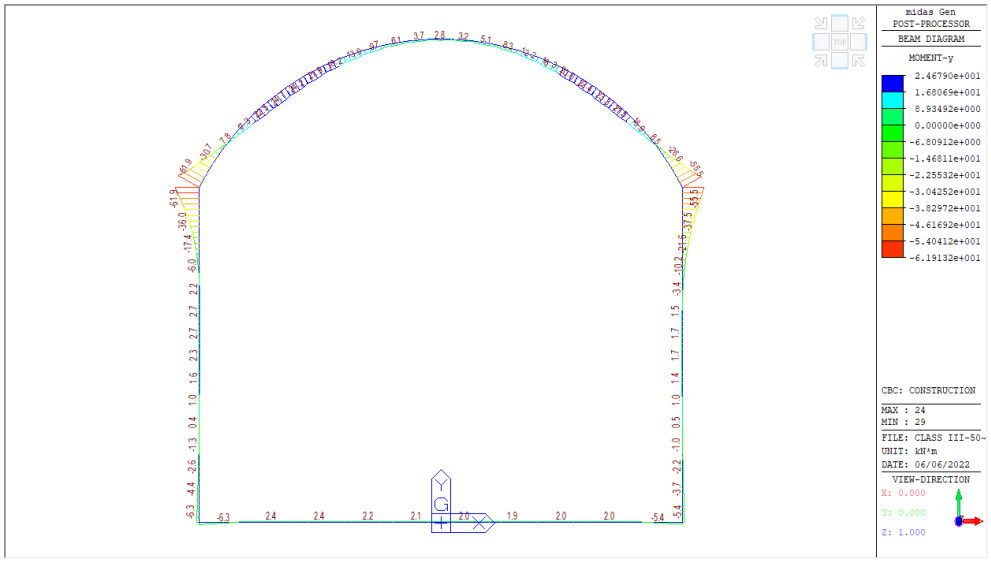


Figure 4.1.1-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

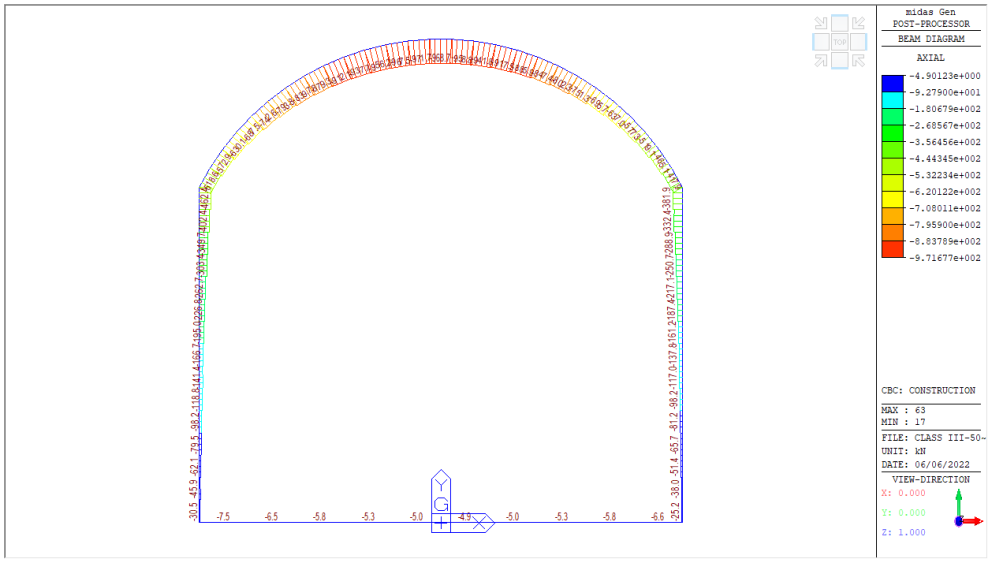


Figure 4.1.1-8 Figure of Axial Force at Concrete Lining Section (CASE3)

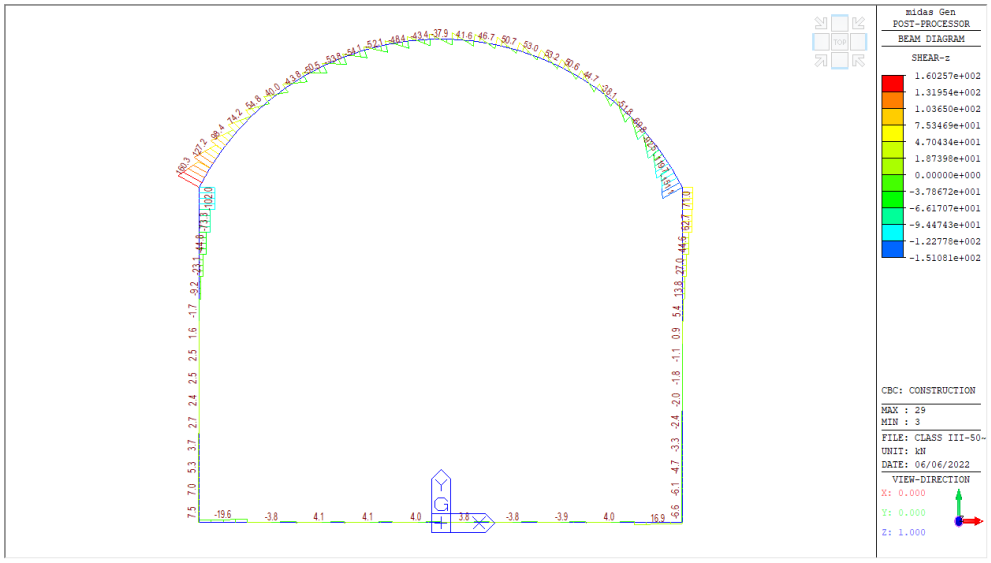


Figure 4.1.1-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.2 Figure of internal forces of concrete lining (Chainage 0+195.039)

The concrete lining from chainage 0+175.039 to 0+195.039, class III, concrete lining thickness 0.8m, double-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

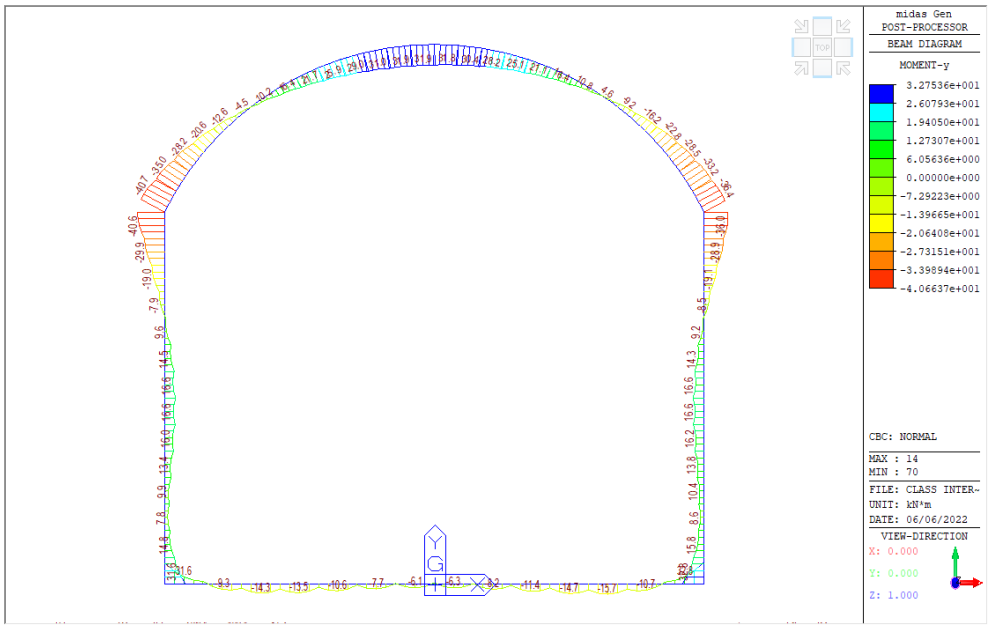


Figure 4.1.2-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

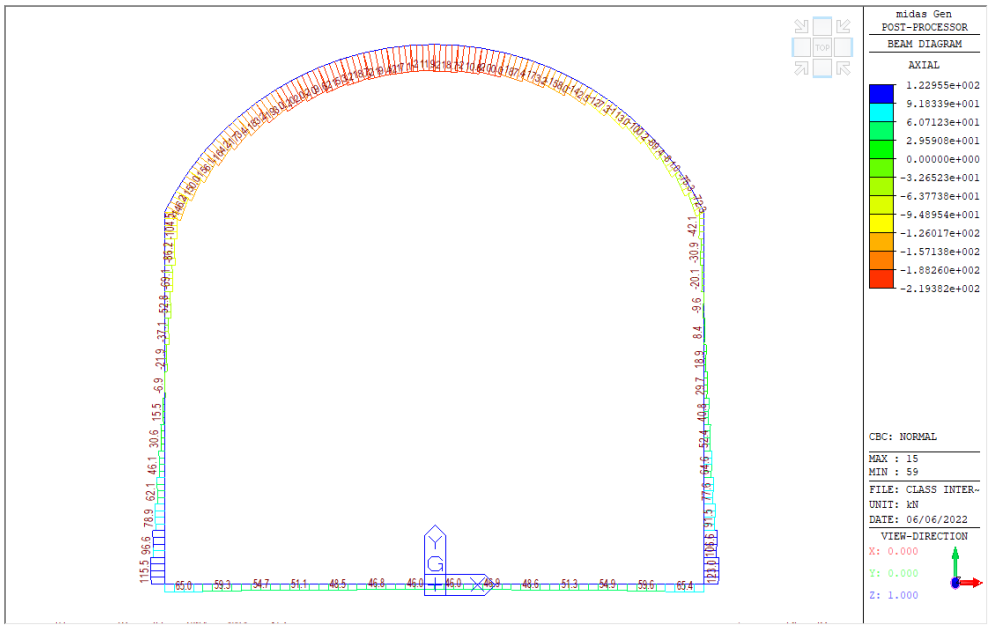


Figure 4.1.2-2 Figure of Axial Force at Concrete Lining Section (CASE1)

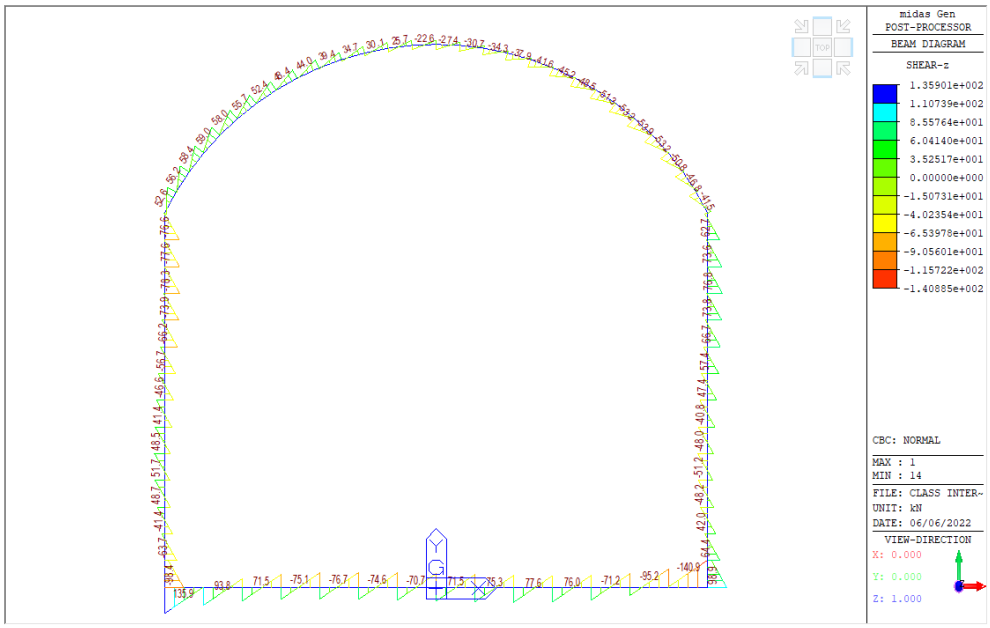


Figure 4.1.2-3 Figure of Shear Force at Concrete Lining Section (CASE1)

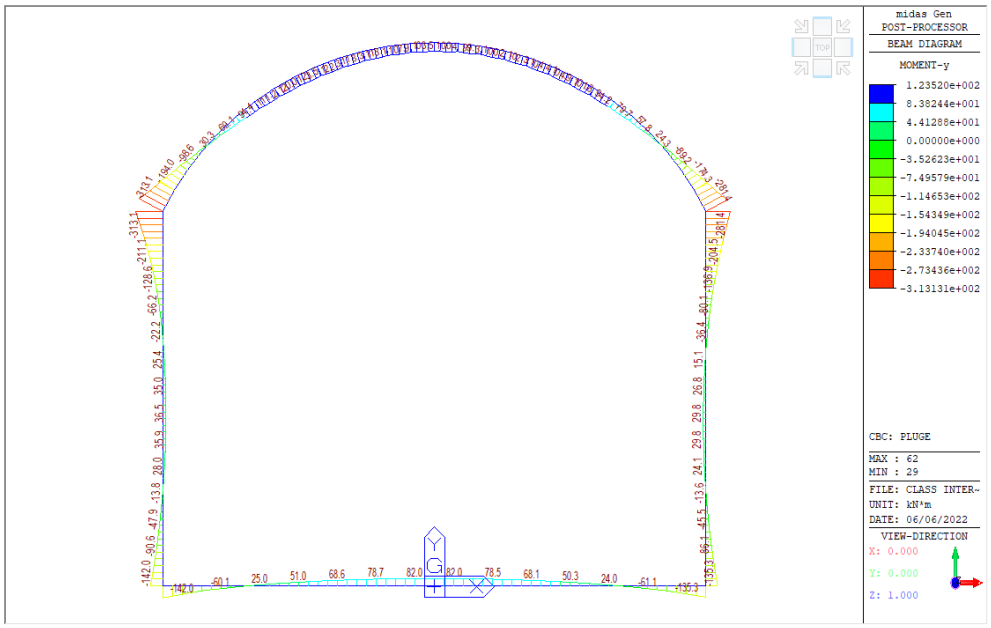


Figure 4.1.2-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

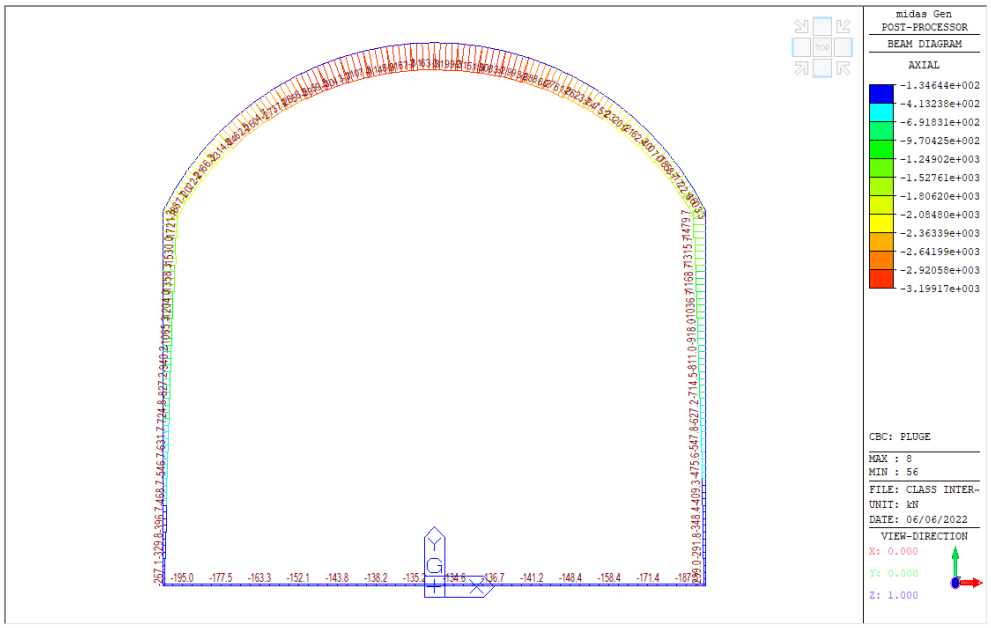


Figure 4.1.2-5 Figure of Axial Force at Concrete Lining Section (CASE2)

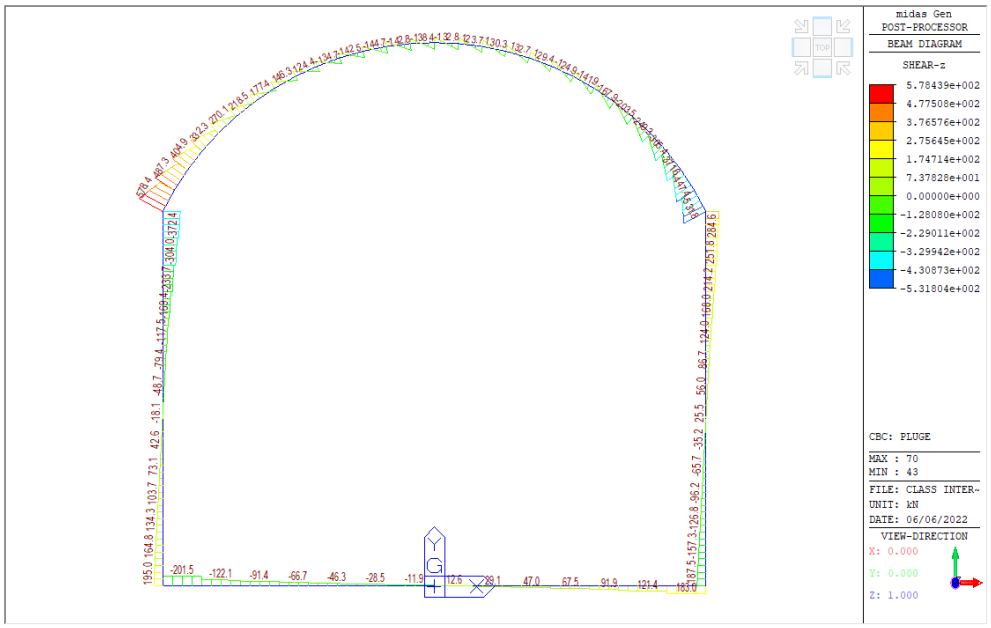


Figure 4.1.2-6 Figure of Shear Force at Concrete Lining Section (CASE2)

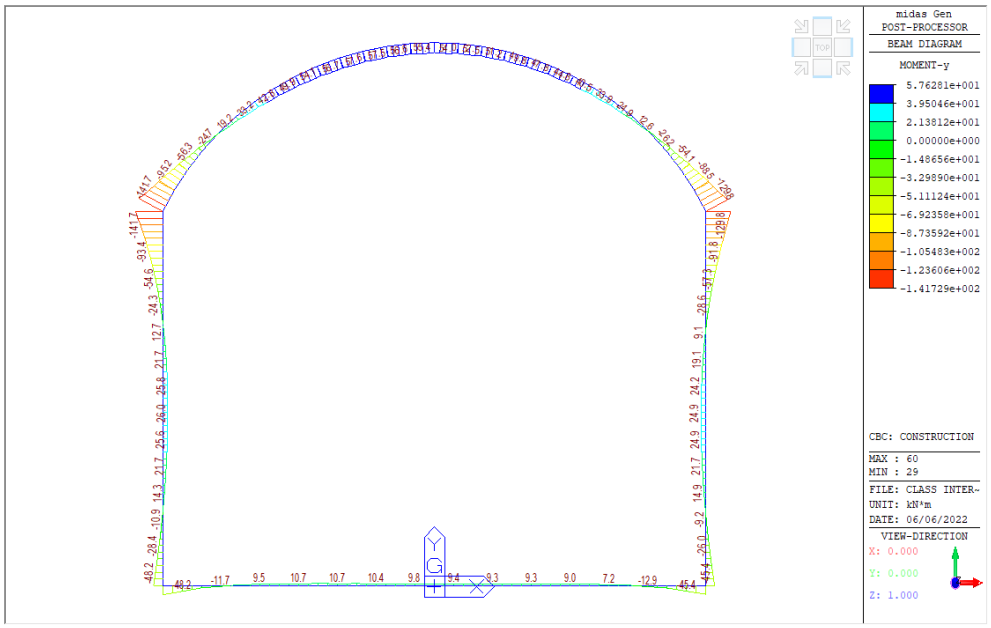


Figure 4.1.2-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

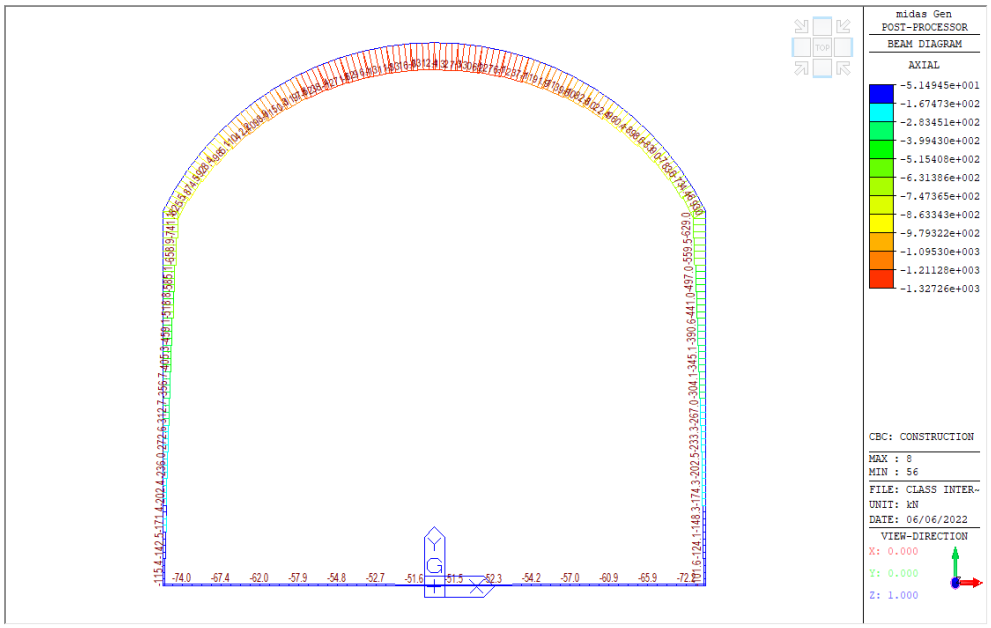


Figure 4.1.2-8 Figure of Axial Force at Concrete Lining Section (CASE3)

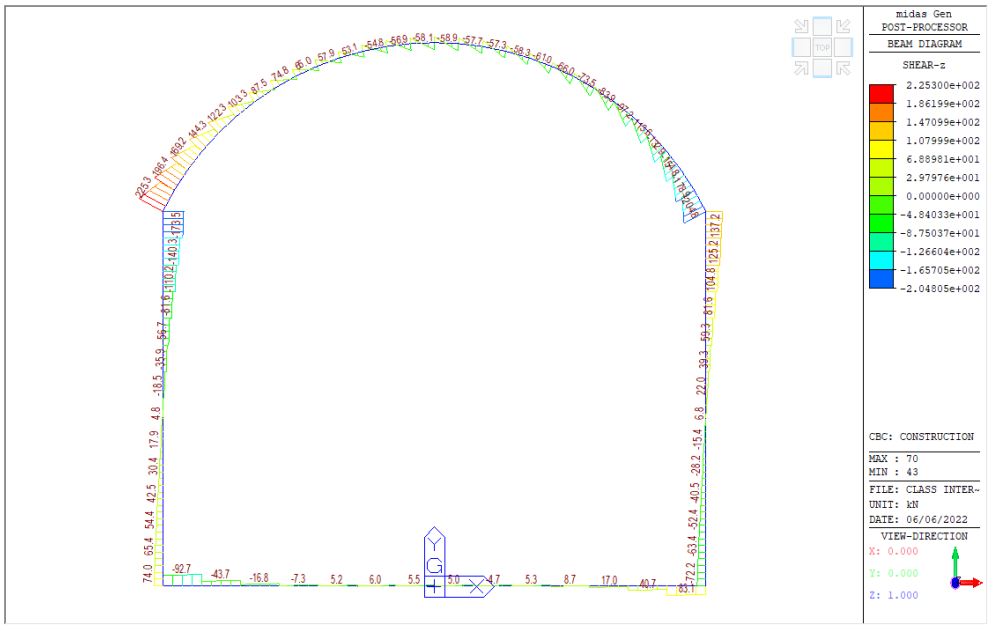


Figure 4.1.2-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.3 Figure of internal forces of concrete lining (Chainage 0+226.935)

The concrete lining from chainage 0+207.59 to 0+226.935, class IV, concrete lining thickness 0.5m, double-sided reinforcement. The bending moment, axial force, shear force and the

critical cases internal force diagrams are shown as follows.

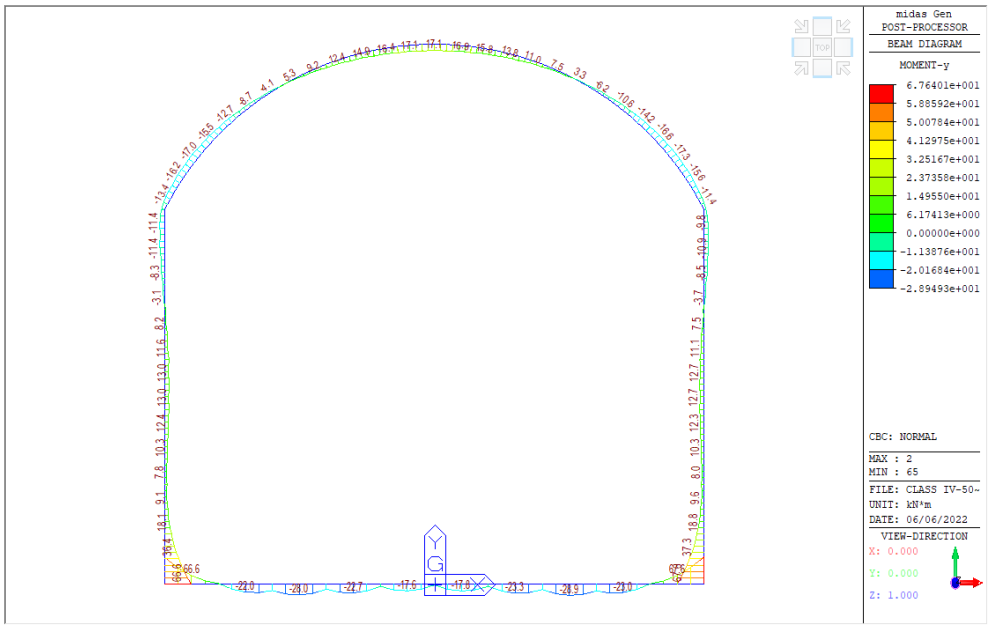


Figure 4.1.3-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

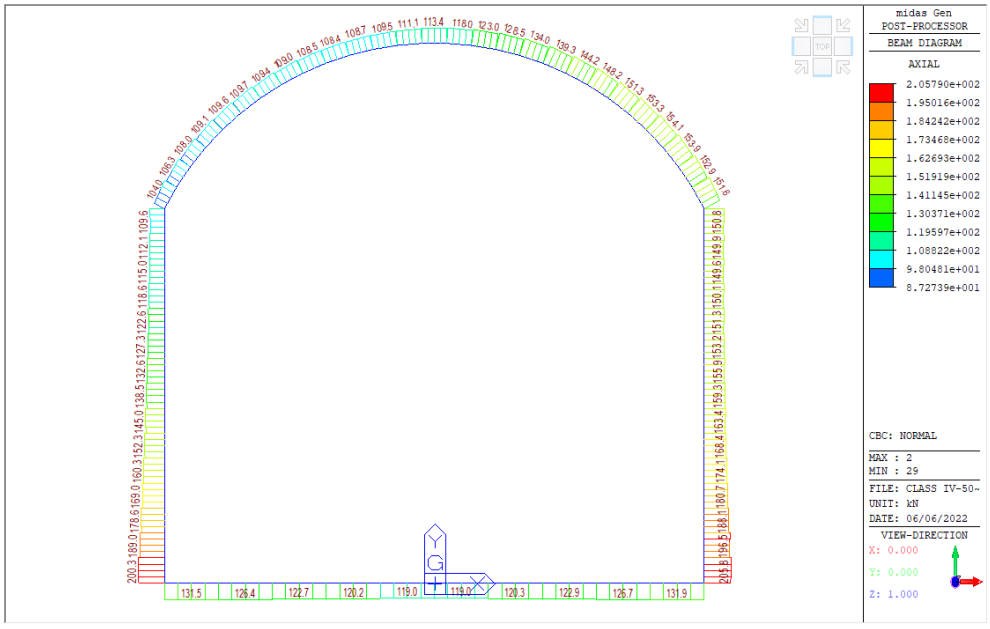


Figure 4.1.3-2 Figure of Axial Force at Concrete Lining Section (CASE1)

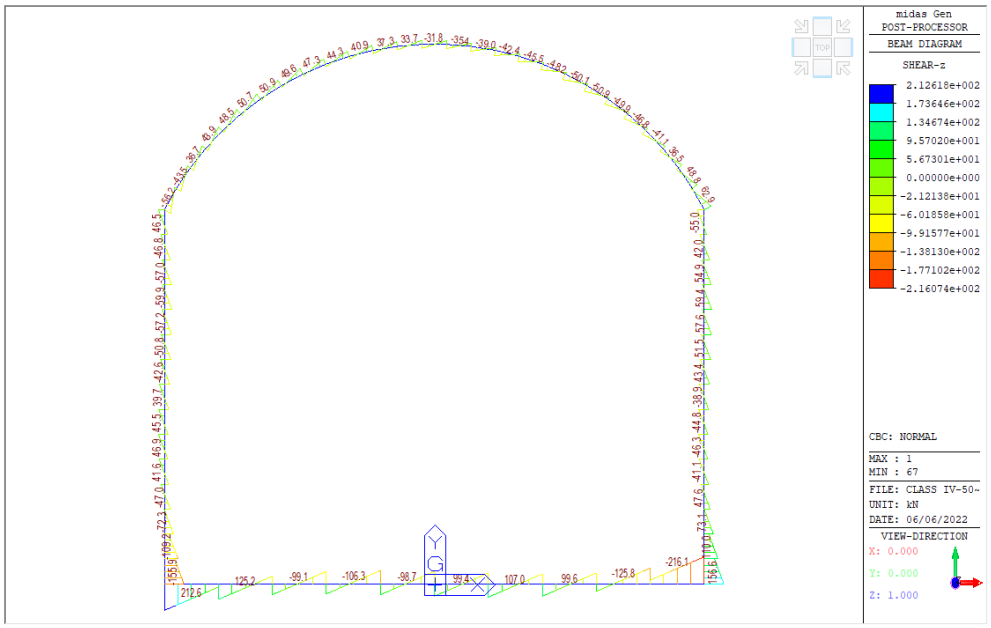


Figure 4.1.3-3 Figure of Shear Force at Concrete Lining Section (CASE1)

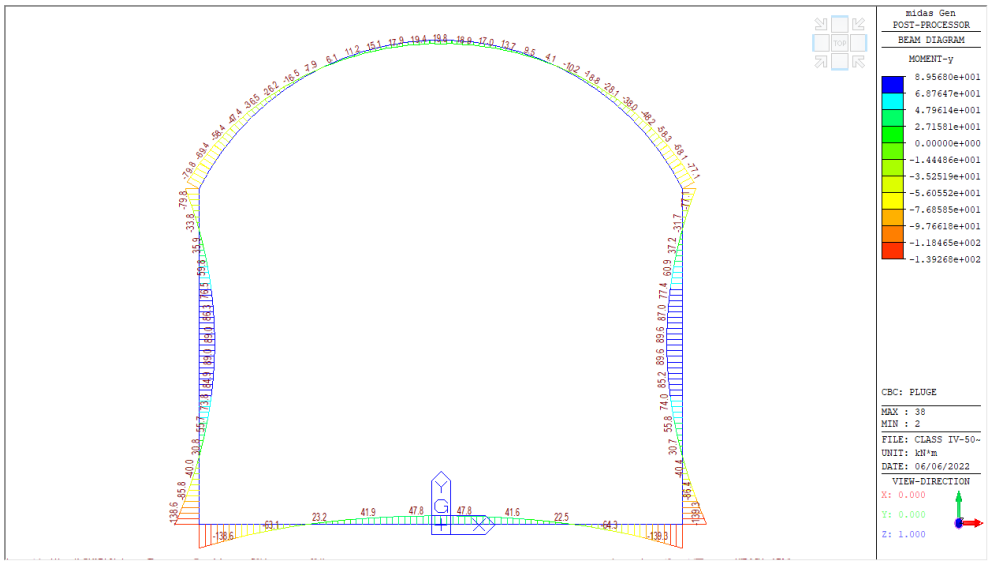


Figure 4.1.3-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

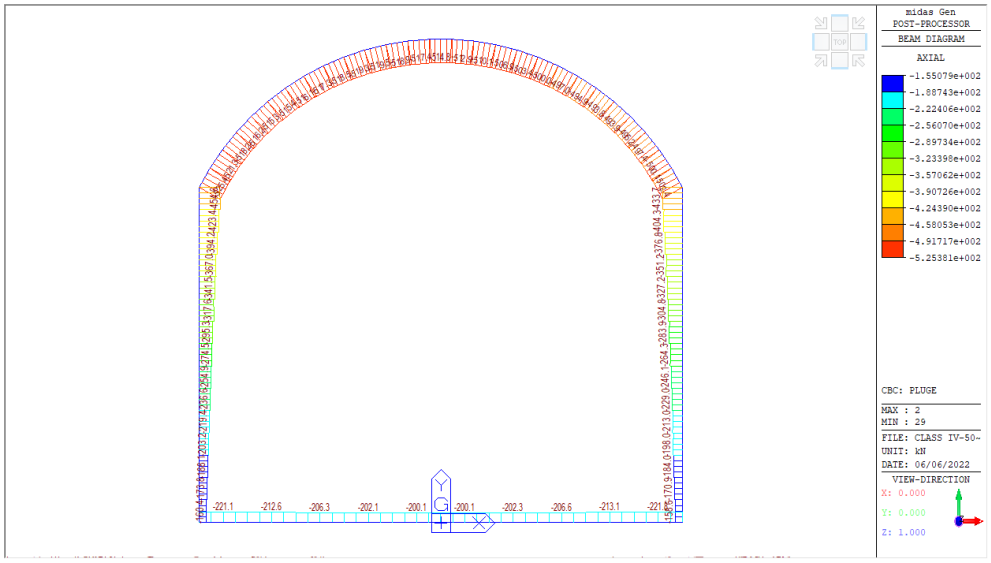


Figure 4.1.3-5 Figure of Axial Force at Concrete Lining Section (CASE2)

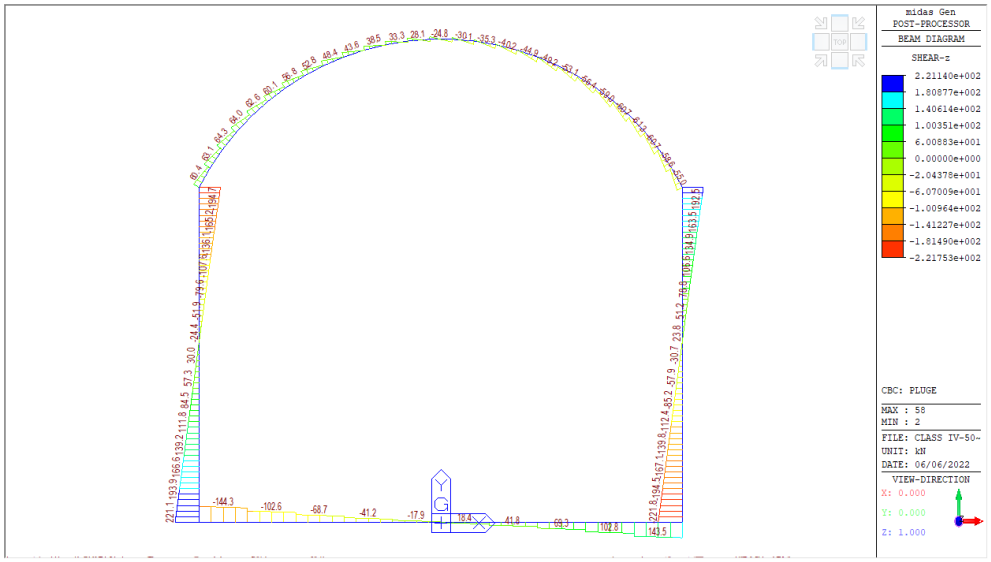


Figure 4.1.3-6 Figure of Shear Force at Concrete Lining Section (CASE2)

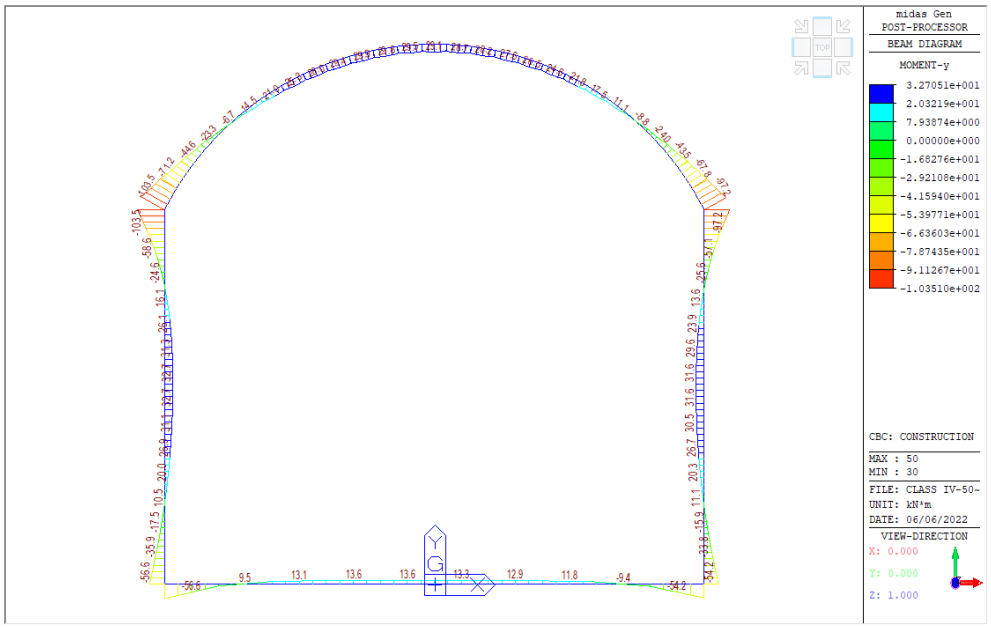


Figure 4.1.3-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

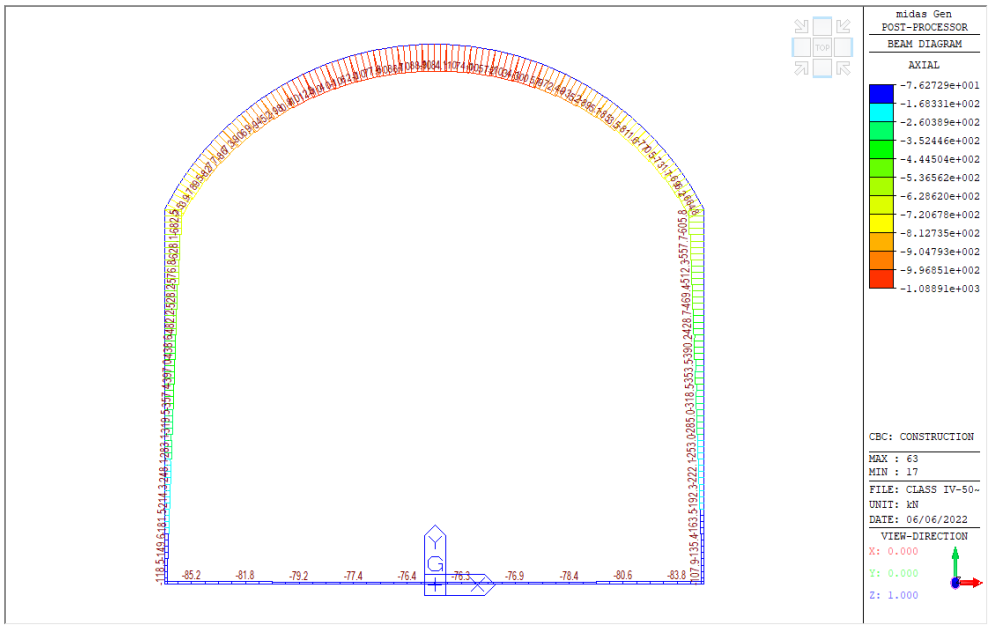


Figure 4.1.3-8 Figure of Axial Force at Concrete Lining Section (CASE3)

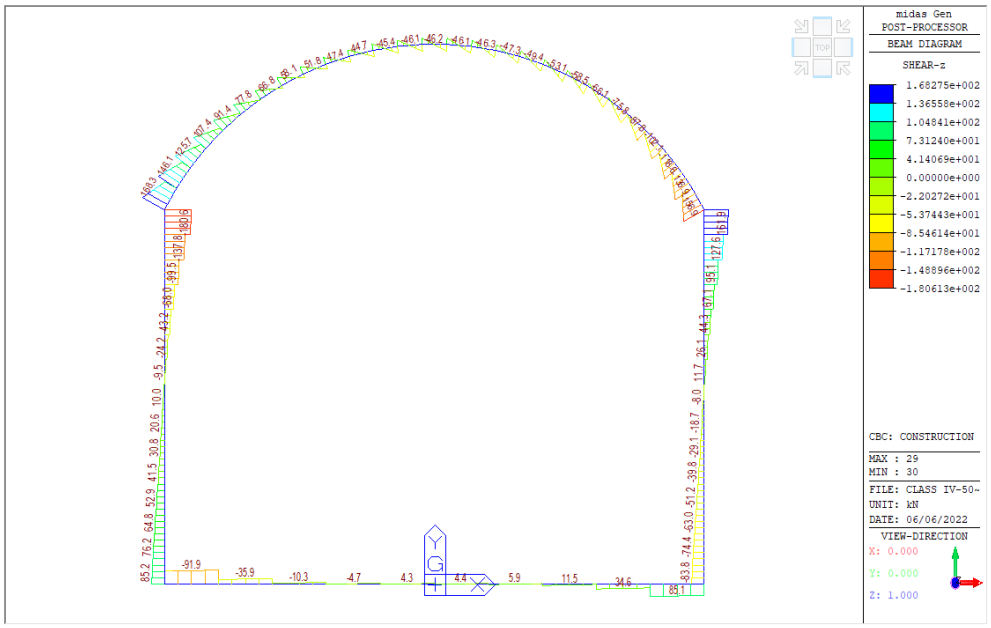


Figure 4.1.3-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.4 Figure of internal forces of concrete lining (Chainage 0+385.330)

The concrete lining from chainage 0+226.935 to 0+385.330, class III, concrete lining thickness 0.3m, single-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

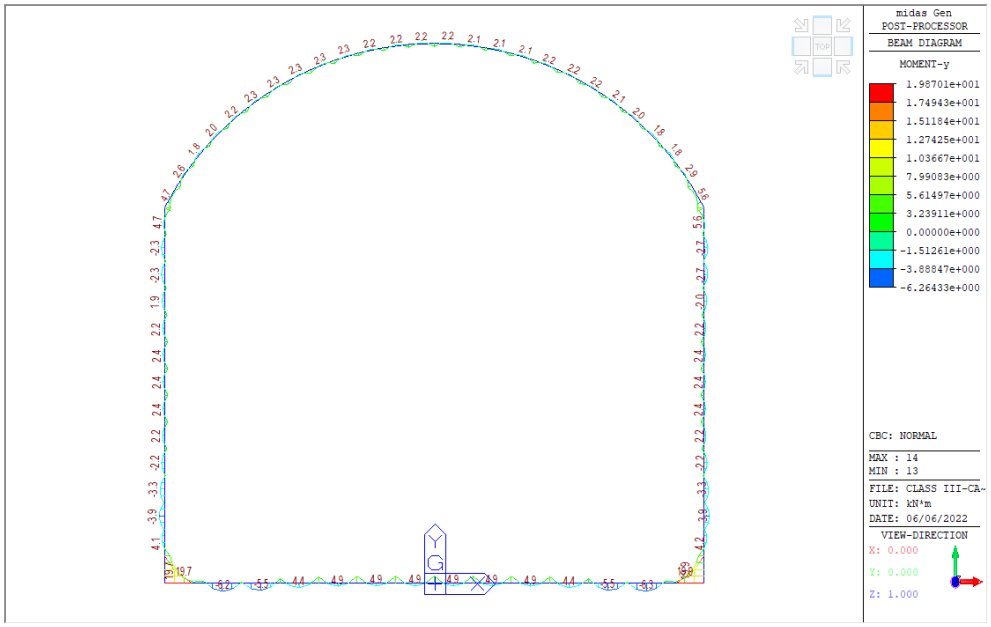


Figure 4.1.4-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

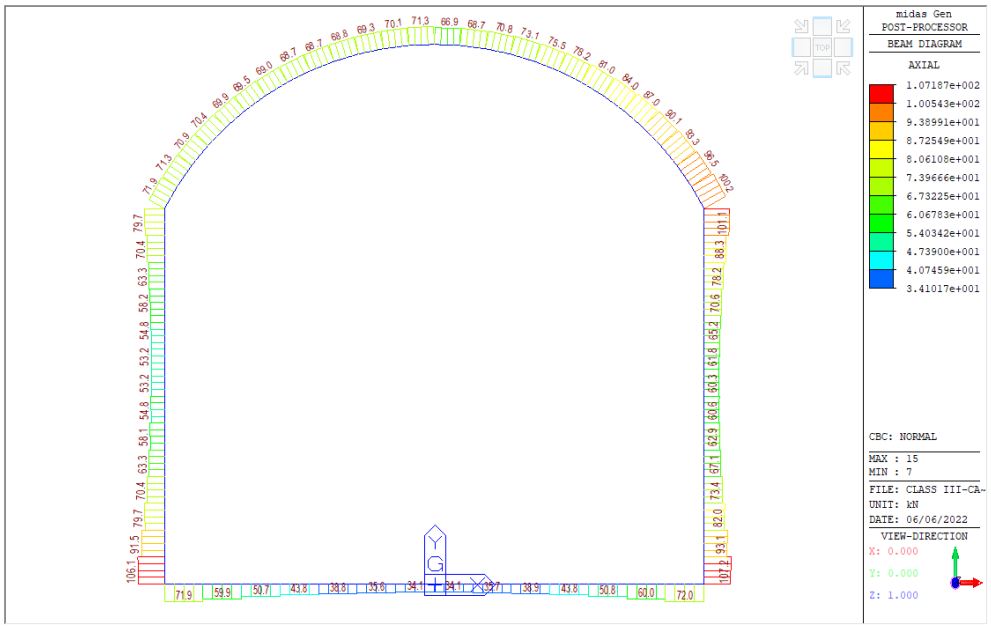


Figure 4.1.4-2 Figure of Axial Force at Concrete Lining Section (CASE1)

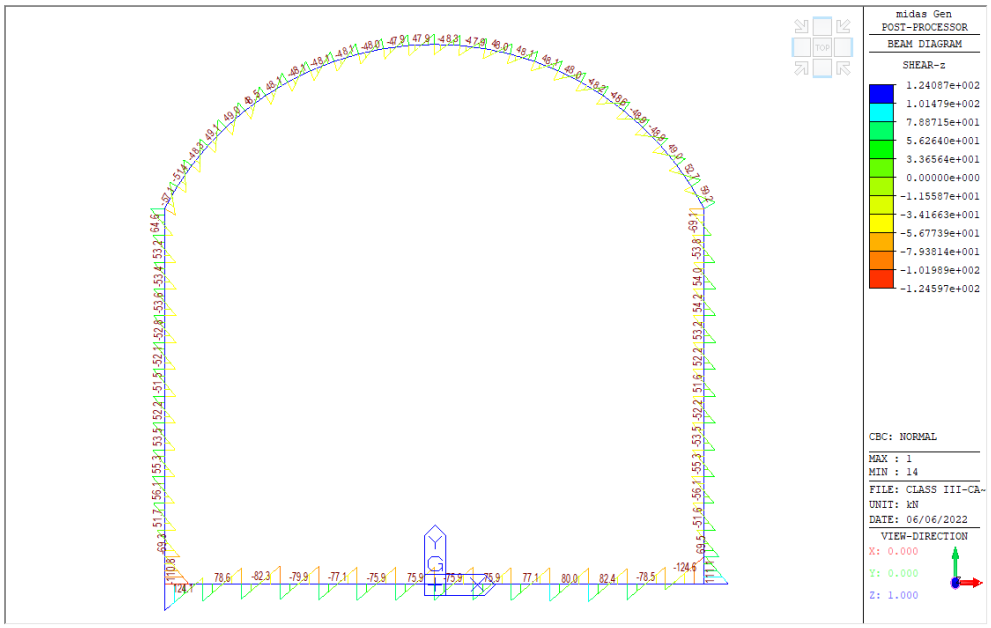


Figure 4.1.4-3 Figure of Shear Force at Concrete Lining Section (CASE1)

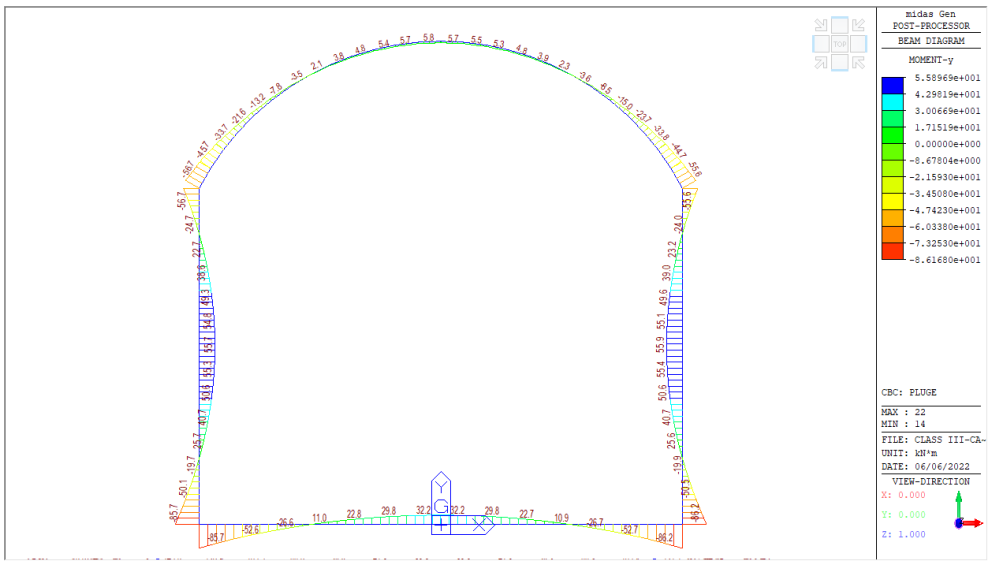


Figure 4.1.4-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

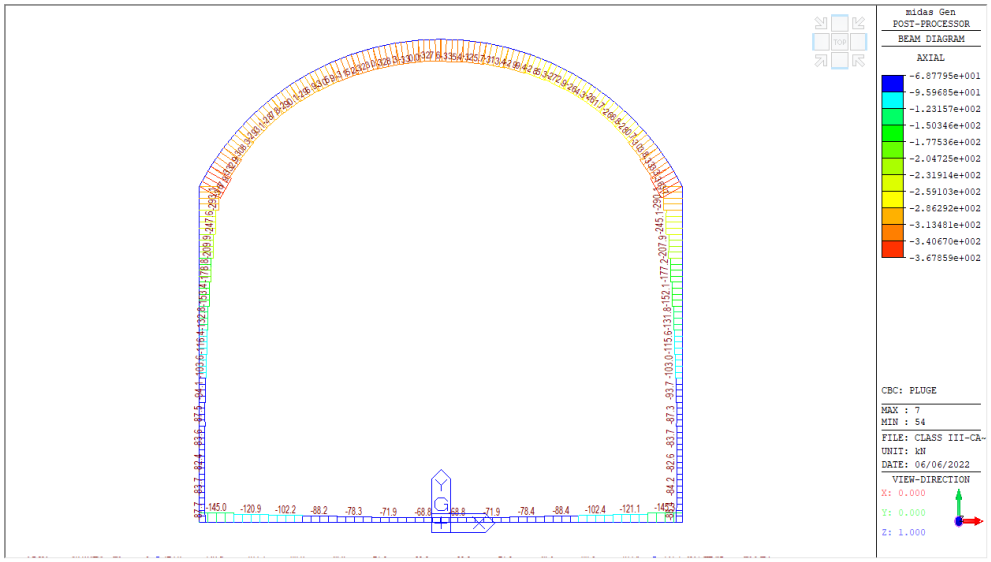


Figure 4.1.4-5 Figure of Axial Force at Concrete Lining Section (CASE2)

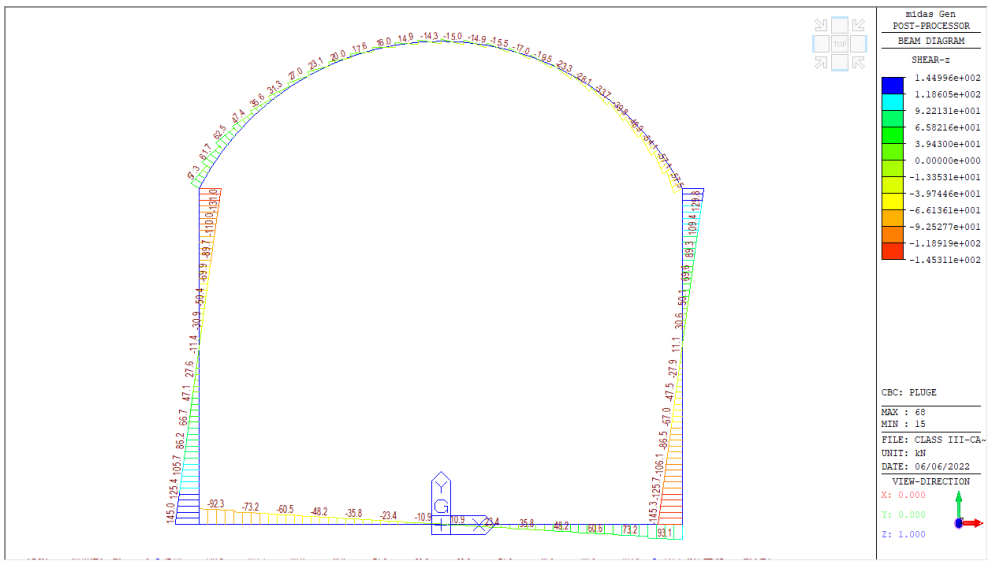


Figure 4.1.4-6 Figure of Shear Force at Concrete Lining Section (CASE2)

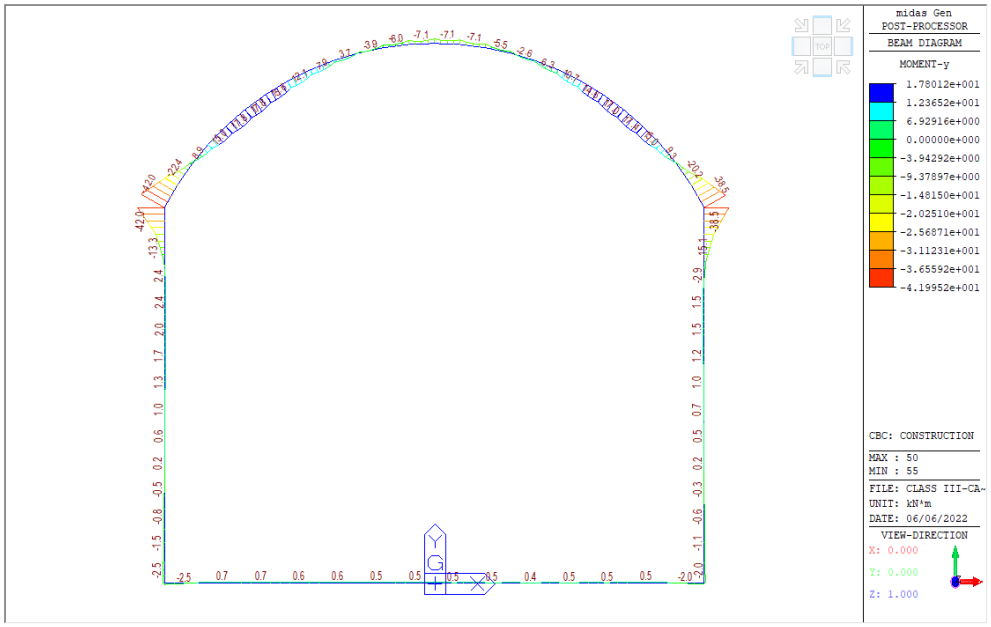


Figure 4.1.4-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

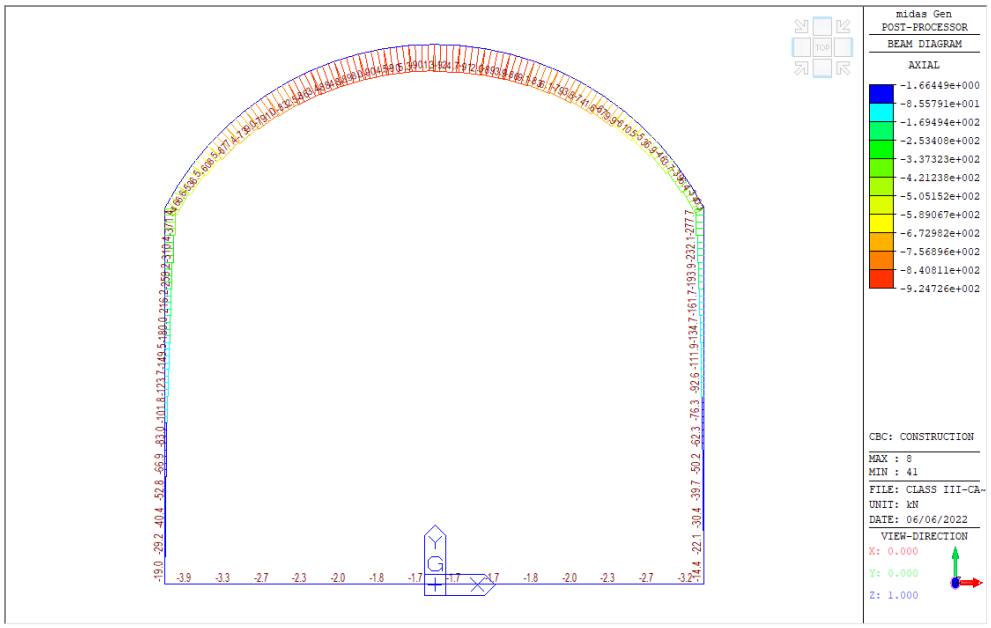


Figure 4.1.4-8 Figure of Axial Force at Concrete Lining Section (CASE3)

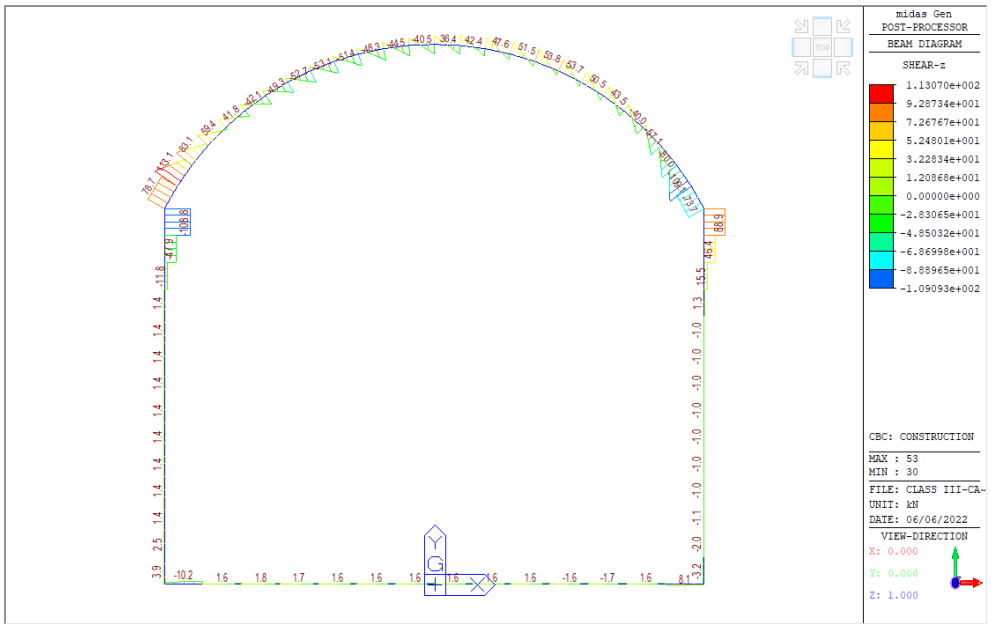


Figure 4.1.4-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.2 Reinforcement Calculation

All internal water pressures which induce a load into the tunnel lining are transferred into the surrounding rock and these are not critical. After comparing the each cases, the external

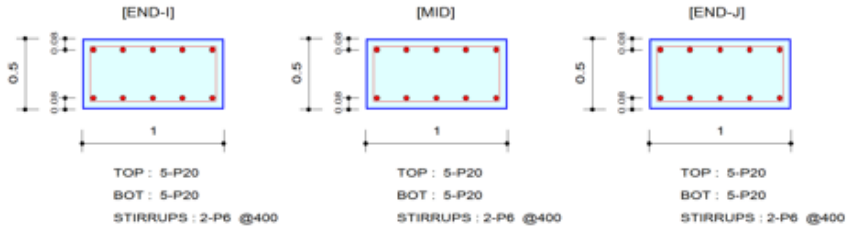
water pressures takes an important role in controlling the force of diversion tunnel, so the result of critical cases are listed as follows. The double sided reinforcing for concrete lining is carried out by Midas Gen, and the single sided reinforcing is in line with the requirement of formula of ACI-318M, the calculating results are as follows in addition.

4.2.1 Figure of reinforcement of concrete lining (Chainage 0+020.00)

1. Design Information

Design Code	: ACI318M-14	Unit System	: kN, m
Material Data	: fc = 24000, fy = 500000, fys = 280000 KPa		
Section Property	: 1X0.5 (No : 1)	Beam Span	: 0.55 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	107.76	97.82	107.76
Factored Strength (PhiMn)	283.27	283.27	283.27
Check Ratio (Mu/PhiMn)	0.3804	0.3453	0.3804
(+) Load Combination No.	1	1	1
Moment (Mu)	59.36	59.36	59.25
Factored Strength (PhiMn)	283.27	283.27	283.27
Check Ratio (Mu/PhiMn)	0.2096	0.2096	0.2092
Using Rebar Top (As_top)	0.0016	0.0016	0.0016
Using Rebar Bot (As_bot)	0.0016	0.0016	0.0016

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	1	1	2
Factored Shear Force (Vu)	158.95	154.16	160.26
Shear Strength by Conc.(PhiVc)	262.34	262.34	262.34
Shear Strength by Rebar.(PhiVs)	12.47	12.47	12.47
Using Shear Reinf. (AsV)	0.0001	0.0001	0.0001
Using Stirrups Spacing	2-P6 @400	2-P6 @400	2-P6 @400
Check Ratio	0.5784	0.5610	0.5832

4.2.2 Figure of reinforcement of concrete lining (Chainage 0+195.039)

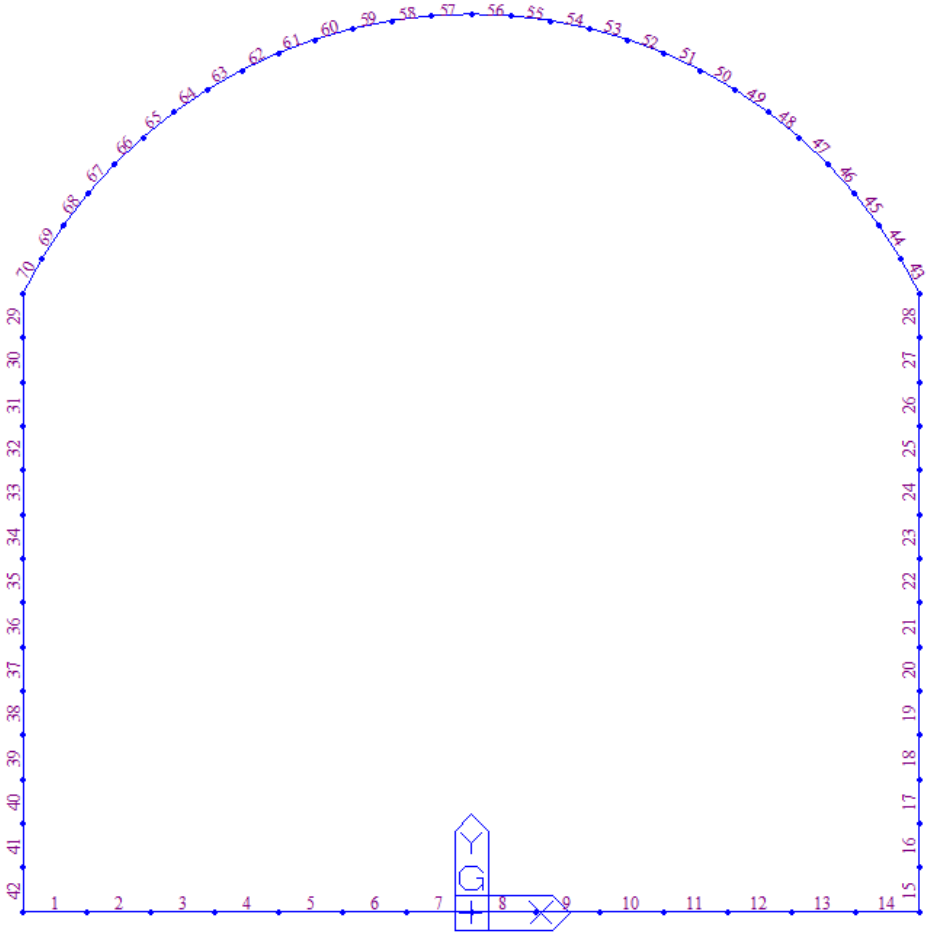


Figure 4.2.2-1 Display of element numbers

1. Design Information

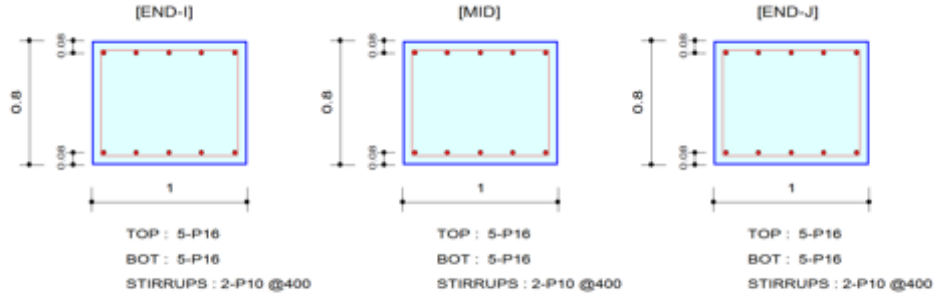
Member Number: 7

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 280000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.414286 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	3	3	3
Moment (Mu)	4.55	6.13	4.15
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.0142	0.0191	0.0130
(+) Load Combination No.	1	1	1
Moment (Mu)	79.88	81.53	82.04
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.2495	0.2547	0.2563
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	3	3	3
Factored Shear Force (Vu)	66.83	36.32	70.70
Shear Strength by Conc.(PhiVc)	449.73	449.73	449.73
Shear Strength by Rebar.(PhiVs)	59.38	59.38	59.38
Using Shear Reinf. (AsV)	0.0004	0.0004	0.0004
Using Stirrups Spacing	2-P10 @400	2-P10 @400	2-P10 @400
Check Ratio	0.1313	0.0713	0.1389

1. Design Information

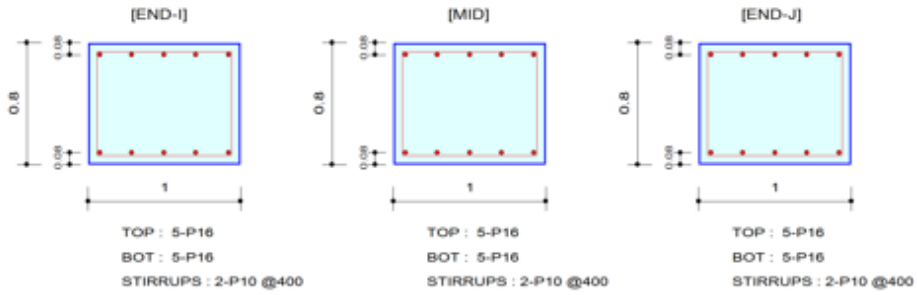
Member Number: 21

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 280000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.285465 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	3	3	3
Moment (Mu)	0.00	0.00	0.00
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.0000	0.0000	0.0000
(+) Load Combination No.	1	1	1
Moment (Mu)	29.85	29.85	28.36
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.0932	0.0932	0.0886
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	3	3	3
Factored Shear Force (Vu)	37.97	21.09	40.78
Shear Strength by Conc.(PhiVc)	449.73	449.73	449.73
Shear Strength by Rebar.(PhiVs)	59.38	59.38	59.38
Using Shear Reinf. (AsV)	0.0004	0.0004	0.0004
Using Stirrups Spacing	2-P10 @400	2-P10 @400	2-P10 @400
Check Ratio	0.0746	0.0414	0.0801

1. Design Information

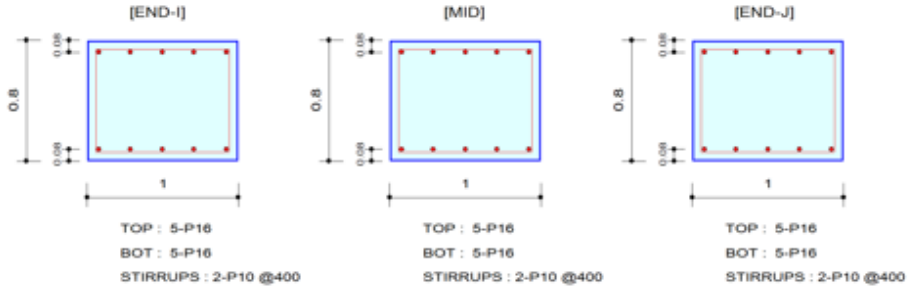
Member Number: 57

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 280000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.256919 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	3	3	3
Moment (Mu)	0.00	0.00	0.00
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.0000	0.0000	0.0000
(+) Load Combination No.	1	1	1
Moment (Mu)	100.57	103.50	102.46
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.3141	0.3233	0.3200
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	1	1	1
Factored Shear Force (Vu)	138.35	76.53	108.94
Shear Strength by Conc.(PhiVc)	449.73	449.73	449.73
Shear Strength by Rebar.(PhiVs)	59.38	59.38	59.38
Using Shear Reinf. (AsV)	0.0004	0.0004	0.0004
Using Stirrups Spacing	2-P10 @400	2-P10 @400	2-P10 @400
Check Ratio	0.2718	0.1503	0.2140

1. Design Information

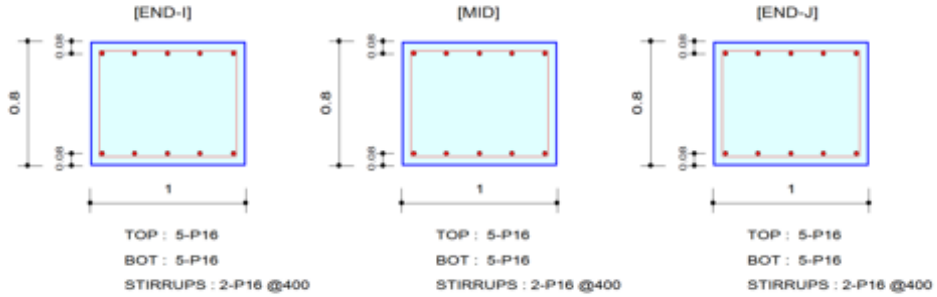
Member Number: 70

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 280000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.256919 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	218.27	277.82	313.13
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.6818	0.8678	0.9781
(+) Load Combination No.	3	3	3
Moment (Mu)	0.00	0.00	0.00
Factored Strength (PhiMn)	320.14	320.14	320.14
Check Ratio (Mu/PhiMn)	0.0000	0.0000	0.0000
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4. Shear Capacity

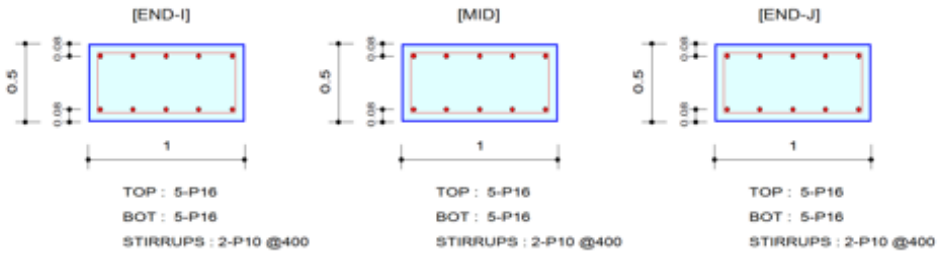
	END-I	MID	END-J
Load Combination No.	1	1	1
Factored Shear Force (Vu)	406.16	521.01	578.44
Shear Strength by Conc.(PhiVc)	449.73	449.73	449.73
Shear Strength by Rebar.(PhiVs)	152.00	152.00	152.00
Using Shear Reinf. (AsV)	0.0010	0.0010	0.0010
Using Stirrups Spacing	2-P16 @400	2-P16 @400	2-P16 @400
Check Ratio	0.6750	0.8659	0.9613

4.2.3 Figure of reinforcement of concrete lining (Chainage 0+226.935)

1. Design Information

Design Code	: ACI318M-14	Unit System	: kN, m
Material Data	: fc = 24000, fy = 500000, fys = 280000 KPa		
Section Property	: 1X0.5 (No : 1)	Beam Span	: 0.55 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	139.27	125.40	139.27
Factored Strength (PhiMn)	184.43	184.43	184.43
Check Ratio (Mu/PhiMn)	0.7551	0.6799	0.7551
(+) Load Combination No.	1	1	1
Moment (Mu)	89.57	89.57	89.57
Factored Strength (PhiMn)	184.43	184.43	184.43
Check Ratio (Mu/PhiMn)	0.4857	0.4857	0.4857
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	1	1	1
Factored Shear Force (Vu)	221.75	214.96	221.14
Shear Strength by Conc.(PhiVc)	262.34	262.34	262.34
Shear Strength by Rebar.(PhiVs)	34.64	34.64	34.64
Using Shear Reinf. (AsV)	0.0004	0.0004	0.0004
Using Stirrups Spacing	2-P10 @400	2-P10 @400	2-P10 @400
Check Ratio	0.7467	0.7238	0.7446

4.2.4 Figure of reinforcement of concrete lining (Chainage 0+385.330)

Because of rock class I, II, III with weep holes, there are lower external water pressure acting on the concrete lining. And Under the initial support, the surrounding rock has been stabilized, so the single-sided reinforcement is adopted.

(1) Calculation of main reinforcement

Reinforcement shall be made according to elastic stress method. Calculating is carried out according to the formula (refer to Figure 4.2.4-1).

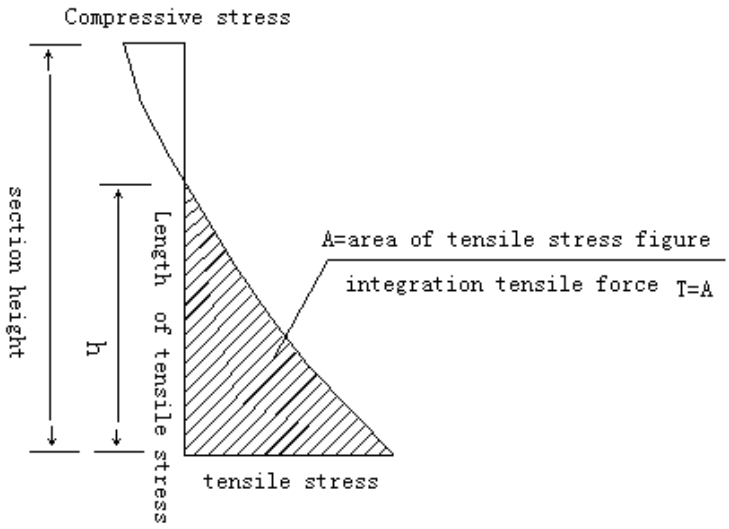


Figure 4.2.4-1 Schematic diagram for tensile force integration

$$A_s = \frac{T}{\phi f_y}$$

$$\mathrm{T} = \mathrm{A} = \mathrm{b}\int_0^h \sigma dx$$

Where,

A_s——Area of non-pre-stressed longitudinal tension reinforcement;

f_y——Specified yield strength of reinforcement;

ϕ——Strength reduction factor, ϕ=0.9;

T——Tensile force;

A——The area of tension stress;

h——The height of tension stress;

b ——The width of tension stress;

σ—— Tension stress on section.

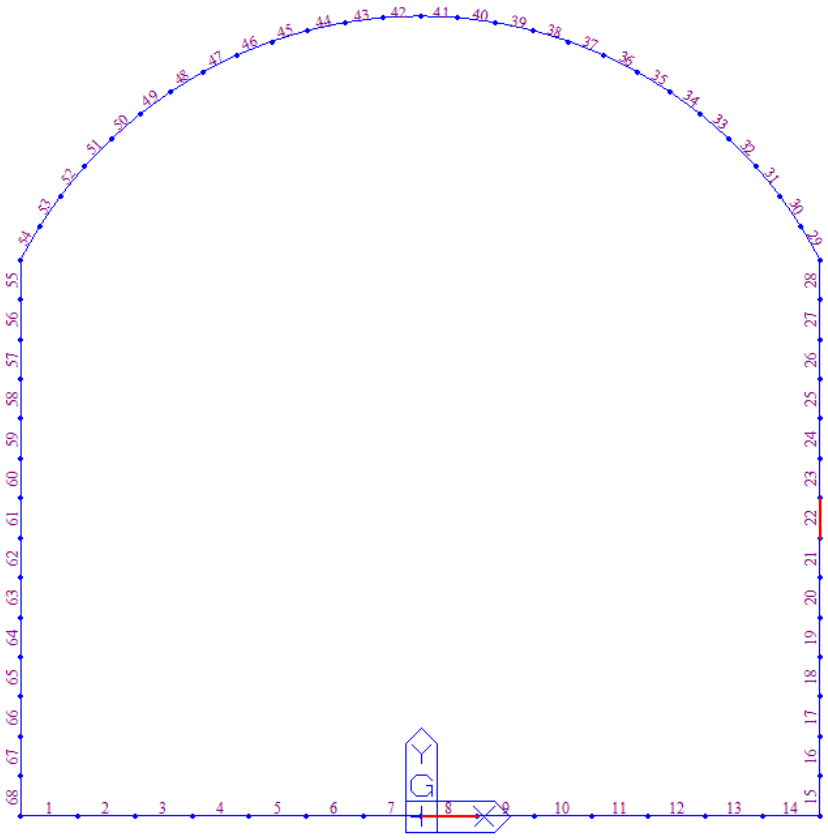
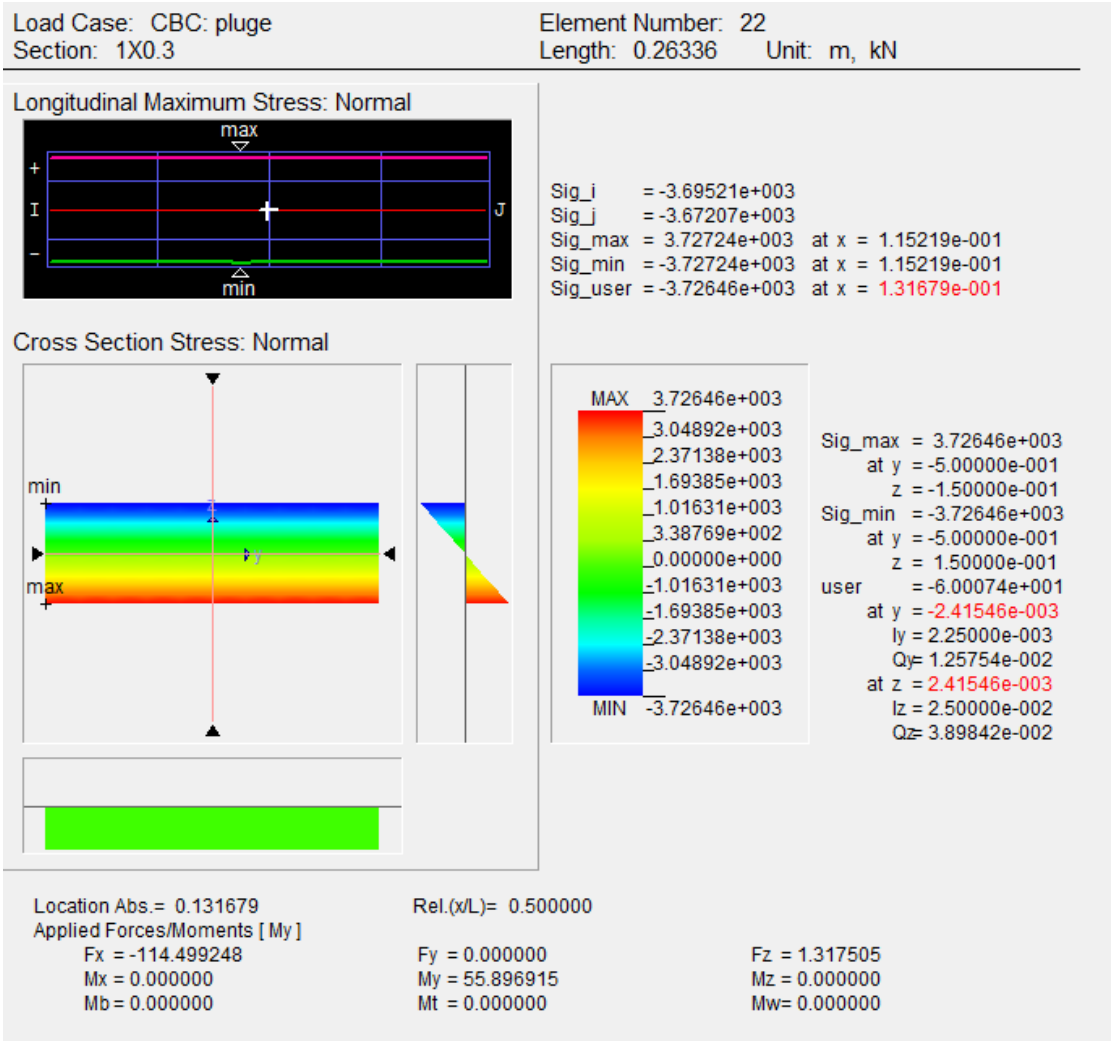


Figure 4.2.4-2 Display of element numbers

According to the internal force calculation results, the element 22 is critical element. The reinforcement of No.22 is calculated as follows.



The tensile stress is σ=3730/2=1865kPa, and the result of reinforcement is listed in following table 4.2-1.

Figure 4.2.-1 Calculation result of main reinforcement

σ(kPa)	b(m)	h(m)	A(m^2)	fy(MPa)	ϕ	T(kN)	As(mm^2)	Reinforcement	A(mm^2)
1865	1.0	0.15	0.15	500	0.9	279.75	622	D16@200	1005

(2) Calculation of shear resistance

Calculate shear resistance at section according to ACI 318

$$V_s \geq \frac{V_u}{\phi} - V_c$$

Wherein:

V_u is maximum shear force at the section;

V_c is shear force borne by concrete;

V_s is shear force borne by reinforcement.

a) For components bearing axial tension, the maximum shear force borne by concrete is calculated by the following formula according to 22.5.7.1 in ACI 318M.

$$V_c = 0.17(1 + \frac{0.29N_u}{A_g})\sqrt{f'_c}b_w d$$

Wherein:

N_u is tension obtained from calculation, which is negative.

b) According to 22.5.6.1 in ACI 318M

$$V_c = 0.17(1 + \frac{N_u}{14A_g})\sqrt{f'_c}b_w d$$

Wherein:

N_u is pressure obtained from calculation, which is positive

(c) For components bearing shear force and bending moment only

$$V_c = \frac{1}{6}\sqrt{f'_c}b_w d$$

According to 22.5.10.5 in ACI 318M, area of shear stirrup is calculated by the following formula

$$V_{ss} = \frac{A_v f_{yt} d}{s}$$

Wherein:

A_v - Area of shear stirrup

s - Spacing of shear stirrup

f_{yt} - Yield strength of shear stirrup

d - Effective height of shear stirrup

Shear resistance of bent reinforcement is calculated by the formula

$$V_{sb} = A_v f_y \sin\alpha$$

Where: α - Included angle between bent reinforcement and component

$$V_s = V_{ss} + V_{sb}$$

The shear force V is 145.3kN, and axial compression force Nu is 88.4kN. The result of reinforcement is listed in following table 4.2-1.

Figure 4.2.-1 Calculation result of shear reinforcement

V(kN)	Nu(kN)	b(m)	h(m)	Ag(m^2)	f'c(MPa)	fy(MPa)	ϕ	Vc(kN)	Vss(kN)	Reinforcement
145.3	88.4	1.0	0.3	0.3	24	280	0.75	184.5	9.21	R10@400X300

5 Conclusions

According to the calculation results of Bending Moment, Axial Force and Shear Force. Reinforcement is follow the standard EM1110-2-2104 and ACI 318M. The Reinforcement Sketch refer to figure 5.1~5.4. Dimensions are in meter, and diameters and spacing of rebar are in millimeter.

Table 5.1 Calculation summary of concrete lining reinforcement

Chaiange	Rock class	Lining Thickness(m)	Main reinforcement diameter & Spacing(mm)	Distributed reinforcement diameter & spacing (mm)	Shear reinforcement diameter & spacing (mm)
D0+020.000	III	0.5m	D20@200 Doubled-sided	D16@200 Doubled-sided	R10@400X400
D0+195.039 Intersection	II~III	0.8m	D16@200 Doubled-sided	D12@300 Doubled-sided	Roof & side wall D16@400X300 Invert R10@400X300
D0+226.935	IV	0.5m	D16@200 Doubled-sided	D12@300 Doubled-sided	R10@400X300
D0+385.553	III	0.3m	D16@200 Single-sided	D12@300 Single-sided	Side wall & Invert R10@400X300

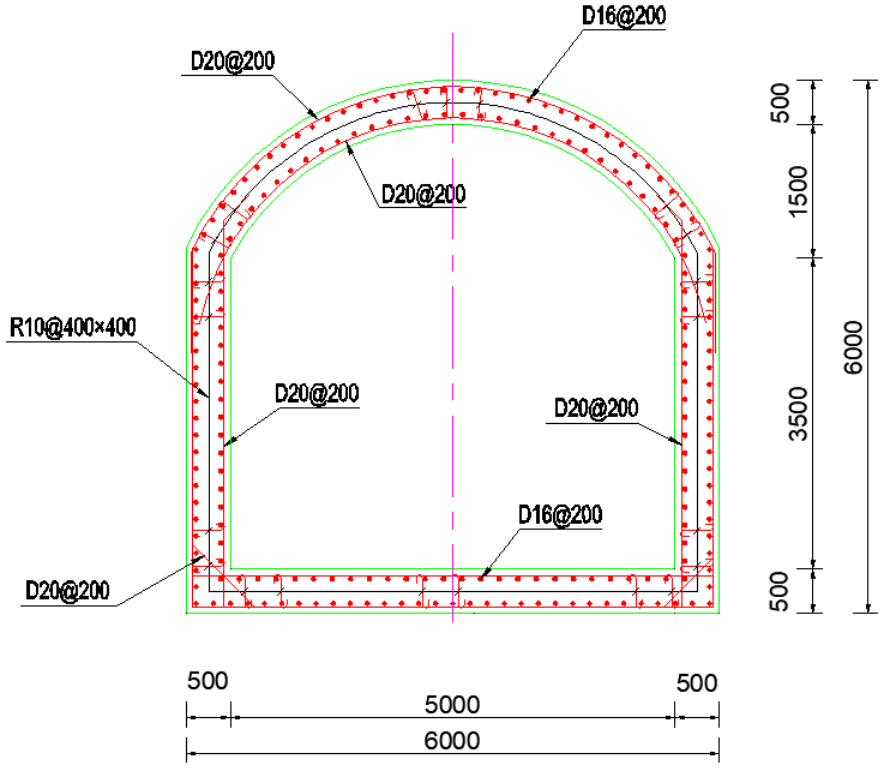


Figure 5.1 Typical cross section (Chainage D0+006.00~D0+020.00)

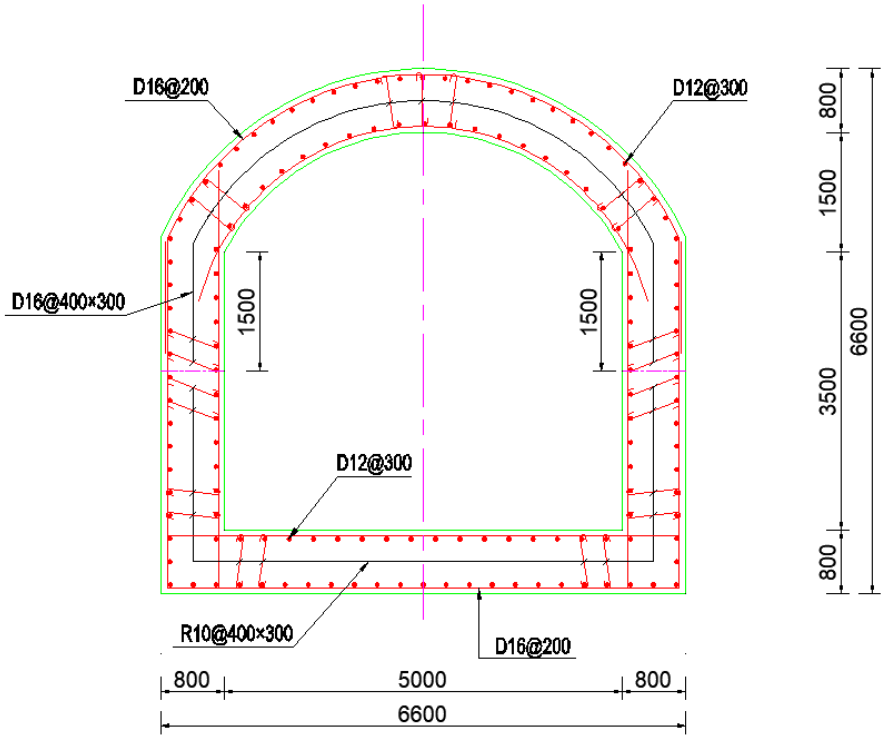


Figure 5.2 Typical cross section of intersection (Chainage D0+175.039~D0+195.039)

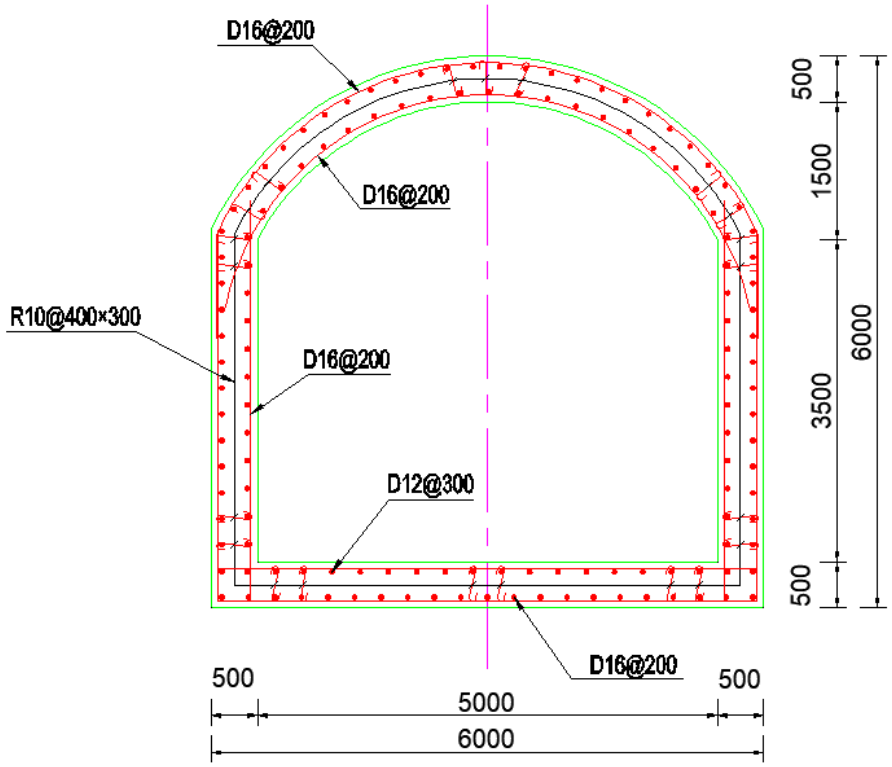


Figure 5.3 Typical cross section (Rock class IV)

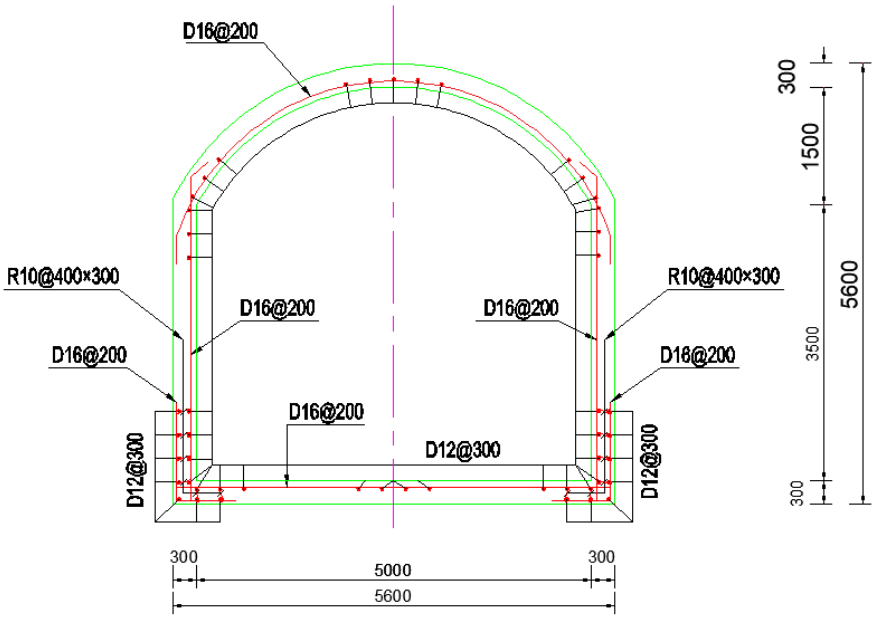


Figure 5.4 Typical cross section (Rock class I&II&III)